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Studies on Acceptability and Refrigerated-Life of Certain Gamma-Irradiated Fresh Strawberries and Cherries

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STUDIES ON ACCEPTABILITY AND REFRIGERATED-LIFE OF CERTAIN GAMMA-IRRADIATED FRESH STRAWBERRIES AND CHERRIES

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INTRODUCTION

From the beginning of time, the history of man has been his struggle to obtain food. After many thousands of years, this is still a major problem which confronts the peoples of the earth. Although much food is available on earth, a great deal never benefits mankind because of deterioration and spoilage. Various kinds of spoilage cause a million tons of grain to be wasted each year. Man has learned to control and overcome some of these destructive forces through a variety of methods of food preservation. Some forms of preservation such as drying, salting, and so forth, probably have been known since the beginning of civilization.

The most ancient method of food preservation, drying, was copied from nature. Early man gathered dried fruits, berries, nuts, legumes, and grains which had matured and dried on the plants. Later they used their shelters to dry food, and pre-Columbus American Indians used the heat from their fires. However, it was not until about the latter part of the eighteenth century that a hot air dehydration room was used. Much of the drying done for modern consumers is in the form of dehydration, which means artificially dried.

About the same time that dehydration came into being, Nicholas Appert began work on another process of preserving food, which came to be known as canning. He received an award from Napoleon when he proved that food heated in sealed containers would not spoil if the containers were not reopened or the seal was not broken. For half a century there was no correct explanation for the success of this process until Pasteur discovered that microscopic growth caused food to spoil. It then became clear that Appert had destroyed micro-organisms by heat, and excluded their re-entry by sealing the containers. The invention of a pressure steam retort, social legislation of the Food and Drug Act, use of the common "sanitary" tin can, and research devoted to the study of nutrients in relation to the canning process have all aided significantly in creating our modern canning industry. Desrosier (7) has aptly said that food preservation practices prior to the discovery of canning were copied from nature. Canning, which has no counterpart in nature, has changed the eating habits of the western world.

Although freezing was used as a method of preserving foods for centuries, the invention of a successful refrigerator in the late 1800's marked the beginning of the vast field of the modern method of refrigeration and freezing. Fish was frozen commercially as early as 1880; meats, in 1891; fruits, in 1905; and vegetables, in 1929. However, in the 1930's, when modern homes contained a refrigerator, frozen foods began to find their place in commerce. It was not until 1940 that freezing assumed its rightful place as a means of preservation.

To preserve foods as nearly as possible in their natural state has long been an aim of man. Each method of preservation has obvious advantages, but not one has wholly accomplished this aim. If a method could be found that preserved food without marked change in its natural characteristics, it would mean man was close to achieving his goal. Fruits and vegetables, which are very perishable, make up 40 percent of the total food consumption. Twenty-five to 50 percent of the fruits and vegetables produced to be eaten fresh, spoil before they can be consumed (45).

A new method of food preservation was made possible in 1945 when the Congress of the United States passed the Atomic Energy Act. Several divisions of the Atomic Energy Commission were concerned with the application of the peaceful uses of atomic energy. In 1953, considerable research on radiation preservation of food was started on a large scale.

Subjecting food to ionizing radiation has been accepted by many as an effective means of preservation. Because of the many complex problems associated with radiation sterilization, preservation by this means is not as feasible at this time as that accomplished by the low doses of radiation for pasteurization. However, there are a number of areas in these low dose treatments which show great promise for use of radiation processing of foods.

1. Conservation of grain and certain packaged products by the destruction of insect infestation.
2. The inhibition of sprouting in potatoes and other root crops.
3. The destruction of trichinae in pork and pork products.
4. The inactivation of Salmonella in egg products.
5. The extension of shelf-life of fresh fruits and vegetables, cut meats, and fresh fish.

The first four areas are approaching the stage at which commercial exploitation might be considered. However, considerable research must still be pursued toward the improvement of certain radiation-treated fresh foods in regard to wholesomeness, nutritive value, color, texture, flavor, and odor.

The studies presented in this thesis were conducted on the acceptability and refrigerated-life of strawberries, and sweet cherries in relation to gamma radiation dose, variety and maturity of crops and physical changes.

REVIEW OF LITERATURE

Historical information

To the food technologist and food scientist, as well as to the physicist, the years from 1895 to 1905 have been eventful. Artificially produced X-rays were reported by Roentgen. A year later Henri Becquerel discovered what was later called radioactivity while attempting to explain a possible connection between X-rays and the luminescence observed in a discharge tube. In the same year, he made the discovery that uranium compounds emit rays spontaneously (15).

Other interesting and important discoveries which gave impetus to this work were suggestions by both G.G. Stokes and G.J. Stoney that X-rays are electromagnetic waves; separation of a bromide from uranium which was called radium by the Curies and G. Belmont; and the discovery that thorium was also radioactive by Madame Curie and G.C. Schmidt (15).

The three types of rays which emanate from radioactive material are alpha radiations which are stopped by the thickness of a piece of paper; beta radiations which are actually fast-moving electrons capable of penetrating up to 0.6 cm of water or an equivalent amount of food;

and gamma radiations which possess exceptional penetration powers in that they can be made to penetrate 30 cm of food, water, or substances (8).

Ionization

The three rays ionize the air to a different extent: the alpha rays are most effective, the beta rays next; and the gamma rays least. Ionization is the removal of electrons which are negatively charged, from an atom, thus forming two charged particles or ions. Because ionizing radiations cause ionization in the material they penetrate, many times free radicals are produced (16), and widespread chemical changes occur--oxidizable substances can be oxidized, and reducible substances can be reduced (7).

Beta versus gamma rays

According to Evans (10), Goldblith and Proctor (17), and Goldblith, et al. (18), the only forms of ionizing radiations that can be used to preserve food are beta particles (cathode rays) and gamma rays.

Evans (10) believes that gamma rays are much superior to electrons as far as penetration is concerned, 3 to 4 inches for gamma rays, 1/6 to 3/8 inches for electrons; but that electrons are superior insofar as dose is concerned. With beta ray machines, sterilizing doses are achieved in a matter of minutes, which would be an advantage for continuous line operation in food processing (44). Goldblith, et al. (18) found that with test organisms cathode rays, X-rays, and gamma rays all had relative bactericidal effectiveness if the samples were sufficiently thin (0.1 cm or less), whereas, if the thickness of the sample was such that variation in ionization from top to bottom was 40 percent; cathode rays were less efficient than gamma rays or X-rays. In general, variations in distribution of ionization are not as great with beta rays for equal thickness of the product (17).

Bactericidal effects

There are two principles involved in the preservation of food; the destruction or growth inhibition of microbes, and the inactivation of enzymes. Radiation accomplishes only the first. Preservation of foods by ionizing radiation is dependent on the bactericidal effect of these radiations.

The concept of utilizing ionizing radiations to destroy micro-organisms dates back to 1896 when a German paper reviewed by O'Meara (29) entitled "On the Question of the Effect of Roentgen Rays on Bacteria and the Possibility of Their Eventual Application" (28). Since 1920, a number of other papers have been published on this subject. Until World War II, research work was handicapped because of the lack of large quantities of radioactive isotopes and of accelerators producing intense beams of radiation (16). However, Edwards, *et al*. (9) reported that in 1930 Wyckoff exposed *Escherichea coli* and *Salmonella aertrycke* to electrons from a cathode ray tube.

In 1942, intensive investigations were initiated at the Massachusetts Institute of Technology and the Electronized Chemical Corporation in Brooklyn into the feasibility of using high-energy X-rays and cathode rays for commercial sterilization of food, while the Atomic Energy Commission sponsored studies at several universities to investigate the use of fission products for sterilization (29).

Micro-organisms in the food are destroyed by two methods. In the direct hit method, organisms are hit directly by a radiation which ultimately causes gene mutation, growth inhibition, nutrient requirement alteration, and/or lethality. They may also be destroyed indirectly by the formation of free radicals produced in the medium being irradiated (33, 16, 7).

A number of research workers have found that several factors may alter the efficiency of the irradiation. Low temperatures resulted in increased destruction. The incorporation of a small amount of protein provided some protection to spores from radiation. A greater dosage was needed as the number of organisms increased. Lethal activities of the rays did not seem to be affected when several experiments were performed at several pH levels and different salt concentrations (9). Some species of micro-organisms are more radio-resistant than others (16). Increased resistance of _E_. _coli_ B/r was noted when the organism was grown anaerobically. With _E_. _coli_ and spores of _B_. _thermoacidurans_, cathode rays, X-rays, and gamma rays had a relative bactericidal effectiveness if the samples were sufficiently thin (18). Bacterial spores are more radio-resistant than vegetative cells (44). Kan and co-workers (20) showed that ultra-rapid germination of bacterial spores of P.A. No. 3679 and Bacillus cereus by amino acids can increase radio-sensitivities of these organisms. They also found that survival of spores was twice as great as untreated spores irradiated in water suspension when sodium thioglycollate was part of the germination medium.

As early as 1916 and 1917, Runner and Davey revealed most of the facts known today about the nature of insect deaths from radiation. It was also found that, in general, graded resistance within a species of 12 grain-infesting pests is exhibited increasing with development stage of the insect from egg to adult (30).

Radiation dose

Ryer (38) maintains, "It can be categorically stated that all life can be destroyed provided a sufficiently high dosage is applied." The more biologically complex a system is the more sensitive it is to radiation injury. As an example, the limits for safety for man are 0.3 rep[a] per week or a total of 800 reps is lethal (44). In general, the following orders of dosages apply to inhibiting food spoilage (38).

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[a]rep (roentgen equivalent physical) is that amount of nuclear radiation which dissipates 93 ergs (some workers use 83 ergs) of energy per gram of tissue producing 1.61×10^{12} ion pairs in the process. It is approximately equal to the amount of energy that would be dissipated by a one roentgen X-ray beam in a gram of tissue.

Inhibition of sprouting for onions and potatoes	12,000 reps
Lethal for insects and trichinae	25,000-30,000 reps
Food pasteurization (vegetative bacteria and fungi)	50,000-500,000 reps
Food sterilization (bacterial spores)	1,000,000-4,000,000 reps
Virus, toxin or enzyme activity	more than 5,000,000 reps

Although such a comparison dramatically illustrates the high dose of radiation required for sterilization of food, there are other factors such as population density, and the individual characteristics of the product to the irradiated which influence radiation sensitivity. These factors have been discussed more fully in the preceding paragraphs. A safety factor is employed in these figures to assure that all spores in a food are killed (44). Because sterilization doses do not inactivate enzymes, the quality of food which is stored will in time and at higher temperatures be affected. Therefore, heat treatment along with radiation looks attractive. There is much promise that dose requirements may be lowered by use of additives such as antibiotics (45).

Even though these high doses are used to preserve food, the product does not become radioactive because the gamma rays are not retained in the food. Desrosier (8) states that there are variations in dose distribution because of types of containers, with all types of sources, and many other factors. He believes that inasmuch as the radiation dose is directly correlated to changes in the food, variations must be kept at a minimum. In order to establish the required dose more accurately, radio-pasteurization dose requirements are being determined for specific organisms (45). When food is irradiated in the frozen state, the experimental evidence indicates that no appreciable change in sterilization dose is necessary (29).

Side effects

Although radiation preserves food, many problems arise from the change or side effects that it causes in the alteration in flavor, odor, color, and texture, and the destruction of the nutrients of the food (21, 44, 35, 34, 36, 5). "The extent of these adverse effects depends on the nature of the food, the condition under which it is irradiated, and the level of radiation used" (36). However, Schweigert (44) believes that relatively small chemical changes occur with only 0.003 percent of chemical bonds broken by sterilizing dosages.

The following is a discussion by Proctor and Goldblith (33) of the reaction when water is bombarded by ionizing radiations. A positive ion is formed and an electron is liberated.

$$H_2O \longrightarrow H_2O^+ + e^- \qquad (1)$$

The electron reacts with another molecule of water forming a negative water ion.

$$e^- + H_2O \longrightarrow H_2O^- \qquad (2)$$

The positive water ion (1) dissociates into a hydrogen ion and a free hydroxyl radical.

$$H_2O^+ \text{ ---------- } H^+ + OH \qquad (3)$$

The negative water ion (2) dissociates into a hydroxyl ion and a hydrogen atom.

$$H_2O^- \text{ ---------- } OH^- + H \qquad (4)$$

The hydroxyl radical is a strong oxidizing agent and will oxidize any oxidizable substance. The hydrogen atom is a strong reducing agent, and as such will reduce any reducible substance.

When off-flavors result after being bombarded by ionizing radiations, the following may occur:

Flavor molecule + OH . . oxidized off-flavor (5)

Some foods such as milk, dairy products, and meat, are sensitive to radiation and much more likely to develop off-flavors and odors than products such as bread, liver, and green beans (44, 47).

Volatile components that appear when beef is irradiated are hydrogen sulfide, aliphatic mercaptans, sulfides, and disulfides. Peroxides and/or carbonyls are produced when foods high in fats are irradiated (21).

One of the techniques that has been successful in eliminating these off-flavors in several foods was proposed by Proctor and Goldblith (33) who added free radical acceptors (FRA) which would compete with the flavor molecule for the OH radical, to the food prior to irradiation. Huber, Brasch, and Waly (19) who experimented with this same technique, found the free radical acceptors eliminated off-flavors in many foods.

Flavor molecule + OH + FRA reduced----------flavor

molecule FRA oxidized + OH^- (6)

Ascorbic acid, D-isoascorbic acid, sodium D-isoascorbate, niacin, sodium sulfite, spices, press juices of organs, tocopherol, esters of gallic acid and certain other polyphenols which were designated as free radical acceptors, had a protective action (19, 33).

Schultz, Cain, Nordan, and Morgan (43) disagreed with the findings of Huber and co-workers. They found no significant difference in flavor of meats canned in air, vacuum or nitrogen; no difference in flavor between meats irradiated while in frozen or unfrozen state. They also found no differences as a result of pre-treating with partial or complete cooking, and with or without dehydration with those meats that were not so pre-treated. When they combined dehydration with irradiation, and heat with irradiation, radiation flavor was not reduced, but may have been intensified.

In some cases the techniques which reduce these changes also protect the micro-organism to some extent (44, 36).

Certain semi-permeable films such as saran, parchment, cellophane and mylar which will allow normal respiration of the product but prohibit the entry of microbes retained the natural flavor of fresh fruits and vegetables

(42).

The same chemical reactions that are responsible for the changes in flavor may also affect the color of irradiated foods (16).

Huber, Brasch, and Waly (19) found that the techniques which protected flavor were valuable for color protection. Color changes were minimized when the substance was irradiated in the frozen state (29, 16); irradiated in inert atmospheres; and with the addition of free radical acceptors (16, 19). Post irradiation storage of several weeks at $41^{o}F$ to $68^{o}F$ also proved beneficial in the recovery of color comparable with non-irradiated controls (19).

Highly significant inhibitory effects of a permanent nature upon lycopene, phytofluene, and gamma carotene pigments of ripening fruits were shown by Burns and Desrosier (3) when tomatoes were exposed to ionizing radiations. They also observed that an increase in red pigment production is shown for a time at the highest level, because the substrates utilized in the production of red color are rendered more available to the enzymatic processes involved. Ripe tomatoes were irradiated to doses as high as 4.65×10^{5} rads[a] at the rate of 0.93×10^{6} rads per hour, but there seemed to be no change in the pigment of the ripe fruit (41). When green and pink tomatoes were irradi-

[a]A rad is equal to the unit of absorbed dose, and is 100 ergs per gram.

ated to 4.65×10^5 and 9.30×10^5 rads, the lycopene pigment system did not develop. As the dose of radiation increased above 1.86×10^5 rads, the red color formation was retarded and in higher doses it was inhibited (40).

Lukton and MacKinney (24) concluded that the destruction of carotenoid pigments on exposure to gamma radiation was caused by second reactions, and depended upon the extent to which free radicals from the hydrocarbon solvent or peroxides from the lipid were available to react with the carotenoid.

Franceschini et al. (11) found that the destruction of carotene and xanthophyll in green beans and broccoli when irradiated ranged from 5 to 95 percent and 25 to 50 percent, respectively, depending on the conditions. The destruction of carotenoids in sweet potatoes and in carrots ranged from 3 to 20 percent and from 0 to 56 percent, respectively. They also noted that different temperatures of radiation; headspace gas such as nitrogen, air, and a vacuum; packing media such as water, brine, or syrup; can lining; and temperature of storage all had a small effect on the color and carotenoid content of the four vegetables.

With a 1,860,000 rads dose, the destruction of chlorophyll amounted to about 40 percent of the original amount in green beans, while about 28 percent of the chlorophyll was destroyed in broccoli. A number of conditions which provided the greatest protection against changes in color and chlorophyll content consisted of immersion in high-pH brine, vacuum packing in plain tin cans, and irradiation in the frozen state (48).

Salunkhe, Gerber, and Pollard (40) found that "the red (anthocyanin) color of cherries is much more susceptible to degradation by radiation than the green (chlorophyll) color of beans."

When five strawberry varieties were irradiated, there was a definite decrease in color change with increase in radiation dose (13). Kraybill (21) reported that strawberries bleach out to grayish-pink color at 5,590,000 rads and at higher radiation doses almost complete bleaching of the plant pigments occurs.

Alteration in texture--softening--is one of the problems that appears when radiation is used in food preservation. Some of the extensive changes which occurred in gamma irradiated apple and carrot tissues were the breakdown of protopectin to pectates and soluble pectin; the breakdown of pectin and pectates to simpler non-pectic materials; and the almost complete destruction of the protopectin component at the highest dose levels. Because ionizing radiations cause the alteration of protopectin in the intercellular areas, tissue cells separate with resultant texture loss and softening (27).

When seven varieties of apples were irradiated with gamma radiations to a dosage from 16.2×10^3 r[a] to 2210 x

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[a]r (roentgen) The roentgen is a measure of X-ray radiation in a particular region. One roentgen produces

10^3 r, the five varieties of carrots, from 100×10^3 to 2070×10^3 r, Boyle et al. (2), found that softening of the tissues resulted. They also observed that:

> In the case of all tissues, a linear relationship was obtained between the percentage change in the crushing load and the logarithm of the gamma radiation dosage within these ranges.

Madsen (25) found that potatoes were progressively softer because the cells of the tubers were separating from each other (probably as a result of calcium pectate degradation) when the dose of irradiation increased to and above 3,720,000 rads.

A positive correlation was found by Salunkhe (39) between the degree of softening of treated Jerusalem artichoke tubers and the radiation dose.

Studies which were conducted by Salunkhe, Gerber, and Pollard (40) showed that as the dose and rate or radiation advanced, the tenderness of asparagus spears increased, and that as the dose of radiation increased, irradiated peach halves became softer.

It has been found by a number of investigators that certain nutrients were easily destroyed by radiation, while others are quite resistant. A large percentage of the vitamin A, ascorbic acid, and tocopherols was easily destroyed in milk at high doses. Carotenoids and riboflavin have been found to be moderately sensitive (47). In other

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one electrostatic unit of charge as a result of ionization in one cubic centimeter of dry air at standard temperature and pressure.

studies (22) with irradiated sweet potatoes, the amount of thiamine, riboflavin, and pyrodoxine destroyed by a sterilizing dose of cathode rays was found to be comparable to the amount destroyed by the thermal processing method. At high doses, starches, including inulin, were hydrolyzed to reducing sugars (31, 14, 39). The concentration of reducing sugars increased as the dose of radiation increased, in most cases. The results of radiation on the nutritive value of casein and egg albumin resembled those changes induced in the protein by heat (26). Foods relatively high in fats undergo irradiation changes through action on the unsaturated fats and fatty acids, producing peroxides and/or carbonyls (21).

Prolonging storage-life

The possibilities of using low levels of radiation to prolong shelf-life appear to offer great potentialities. Sprouting of potatoes was reduced with small radiation dosages as low as 5,000 r; while complete inhibition of sprouting was observed at 20,000 r with resultant prolonging of the useful storage-life of potatoes (31, 46, 25, 4).

Insect deinfestation of grains and cereals by irradiation at 116,000 rads is another application that offers promise for extending the useful storage-life of food products (21).

Because fungi were destroyed, shelf-life increases were evident in lemons when treated at 140,000 rads. Blue-berries, cherries, and strawberries that received from 100,000 to 150,000 rads dosage and then packed under vacuum were acceptable from three to five months at refrigeration temperature (21). Grapes irradiated to 100, 000 rads dose level were in excellent condition at the end of a month's storage. Mold growth was controlled on cherries which had been irradiated to 300,000 and 500,000 rads (13). Gerber, et al. (14) observed that mold started more slowly at all temperatures on irradiated strawberries than on non-irradiated strawberries when both had previously been dipped in a bread mold spore suspension.

Using pasteurizing doses of radiation, several investigators found that storage-life of a number of products could be extended considerably. Proctor et al. (35) using dose levels of 1.0×10^6 rep to 1.5×10^6 rep, hermatically sealing the container and storing at 36 to 40°F found it possible to extend the storage-life of spinach (preliminary blanching) for at least six weeks; fresh pork sausage, 120 days; ground beef, 12 weeks; and frankfurters, three months. However, 0.3 percent sodium fumarate and 0.5 percent monosodium glutamate were added to the ground beef to obviate radiation off-flavor; 0.25 percent sodium ascorbate was added to the frankfurters to prevent off-flavor. After eight months' storage at 50°F, irradiated pork sausage was still acceptable (23). Irradiated chicken, scallops, and sweet potatoes, stored at 50°F and 68°F were acceptable after 8 to 10 months (22, 23). Kraybill

(21) reported that cooked oysters and blue crabmeat treated at 500,000 rads and then refrigerated, were acceptable for at least four months; while mackerel, cod, salmon, and sole with the same treatment and one month's storage were acceptable. Raw oysters have their shelf-life extended sevenfold by irradiation at 930,000 rads. Meats treated at 100,000 to 500,000 rads have their shelf-life increased fivefold.

O'Meara (29) states that it is necessary to prevent enzyme spoilage as well as microbial spoilage. As stated above, because sterilizing doses do not inactivate enzymes, the quality of food which is stored will in time and at higher temperatures be affected (45).

Fields (12) discovered that high levels of cathode rays were required to reduce the activity of alpha amylase and sucrase of a test organism, Aspergillus oryzae (Ahlbury) Cohn ATCC strain 11601.

Wasserman (47) found that because enzymes are so radio-resistant, 5 to 30 times the sterilizing radiation dose is required before enzymes are inactivated.

Burns and Desrosier (3) have shown that because irradiation does not affect enzymes, an increase in red pigment production was shown for a time at the highest level when the substrates utilized in the production of red color are made more available to the enzymatic processes involved.

When casein and egg albumin were irradiated, it was found that the trypsin hydrolysis rate of casein and egg albumin was increased because of radio-resistance of such enzymes in food, and because of the accelerated activity of naturally occurring proteolytic enzymes on the activated substrates. This enzyme was found to be quite radio-resistant *in vitro*, but more so in natural food substances (26).

To offset these disadvantages, the method in which food is heat-blanched before being irradiated appears to be the most promising, although other methods of blanching which do not involve conventional heating are being considered (47).

METHODS AND MATERIALS

Fruits for the experiments were obtained through a local wholesale dealer and from the Field Stations of the Utah State Agricultural Experiment Station. Only top-quality produce was selected. After sorting, the fruit was placed in perforated No. 10 tin cans containing No. 10 Kraft paper bags or other liners. Cardboard dividers were used in the cans to prevent bruising of the samples during travel. The cans were labeled for dose and rate of radiation and for varieties. The products were sealed and placed in a traveling refrigeration unit with a constant temperature of 40°F and were transported to the Material Testing Station near Arco, Idaho.

In the Gamma Radiation Building at this facility, the cans of fruit to be radiated were placed two at a time in a specially constructed aeration chamber (Figure 1). To maintain normal respiration and metabolic processes of the products, air was circulated through the chamber. A description of the construction of the aeration chamber has been given by Salunkhe and co-workers (42) as follows:

> A chamber was constructed from a 2-ft. section of 7-in. diameter aluminum portable irrigation pipe with a thickness of 0.083 in. An aluminum bottom was welded on one end, then the cylindrical tank was weighted with 35 lb. of lead. A maneuverable aluminum lid

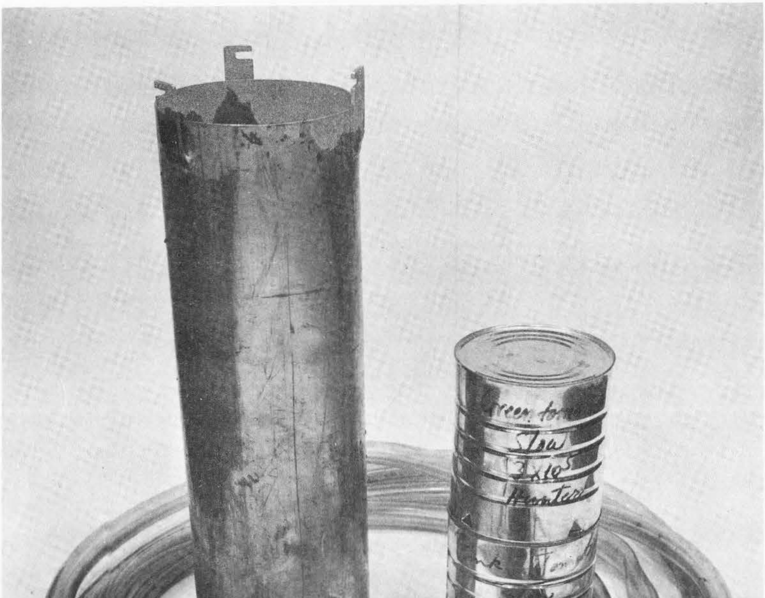
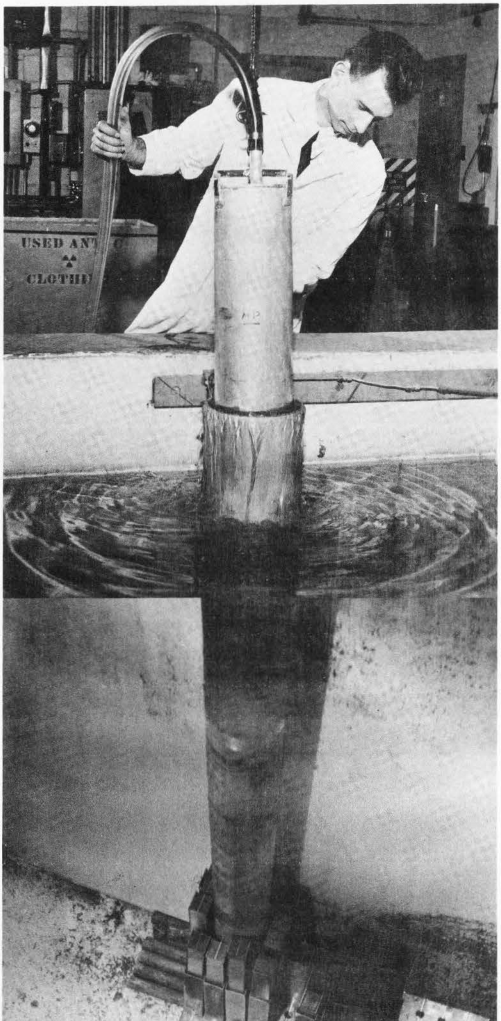


Figure 1. Aeration chamber and equipment used for radiation of the fruit.

> was designed to fit the other end and was made water tight with a rubber gasket. A 6-in. piece of 3/4-in. iron pipe was fastened with a gasket into the lid to which was clamped a 25-ft. length of 1-in. inner diameter Tygon tubing. A 25-ft. length of 1/2-in. outer diameter Tygon tubing was threaded through the larger piece of Tygon tubing.
>
> . . . air under 10 lb./sq. in. pressure was forced down the small tube. Within the chamber, the air was divided with a glass Y-tube and taken by auxiliary tubes to each perforated can of the product.
>
> The exhaust air escaped from the chamber through the space between the small tube and the wall of the large tube.

This chamber was lowered in the UIA column (Figure 2), which is an upright 18 foot length of 8 inch aluminum pipe, lead weighted and sealed at the bottom. The column was anchored in a 40 x 6 foot "swimming pool" type of canal, which contained 18 feet of water to provide the necessary shielding. The column has a separate source of uncontaminated (flushing) water flowing through it continually; hence, at no time does the contaminated canal water touch the containers holding the samples. The above-described column is referred to as the UIA column since the branch of the University of Idaho at Aberdeen provided the facility.

The source of gamma radiation was spent fuel elements, which were no longer useful in the reactor. These elements which had approximately 25 percent of their original U^{235} disintegrated by fissioning were received from the reactor in heavy shielding, and were deposited in the canal at the base of the UIA column (6, 37).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An ionic chamber for dosimeter measurements was used to ascertain the proper rate of radiation, and subsequently to determine the time required for a given dose of radiation, which is expressed in rads. Calculations for dose and rate of radiation, radiation techniques, and other treatments are discussed by Rivers (37).

Following radiation, the cans were returned to the research laboratories of the Department of Horticulture. They were stored at 40°F until opened for sensory evaluation studies at specified intervals. Samples were examined carefully to determine color, texture, odor, and other physical characteristics.

Fruits were prepared for judging after washing and selecting a uniform number of representative samples. They were coded and served raw. Irradiated and non-irradiated samples of the same variety were put on a tray and placed in a darkened judging room. The large judging table was divided into five partitions. Each partition was equipped with a red light in order to keep sample colors as nearly alike visually as possible.

Taste preference of the irradiated and non-irradiated products was evaluated in the Food and Nutrition Laboratories by a panel of 10 judges (Figure 3). Because of its flexibility, simplicity, and reliability of results, the Hedonic scale (Figure 4) suggested by Peryam and Pilgrim (32) was used for scoring. This scale has nine phrases arranged from 1.0 (dislike extremely) to 9.0 (like

Figure 3. Quality Evaluation Room.

Name________________________ Date_______________

Score	Sample ______	Sample ______	Sample ______	Sample ______
9	Like Extremely	Like Extremely	Like Extremely	Like Extremely
8	Like Very Much	Like Very Much	Like Very Much	Like Very Much
7	Like Moderately	Like Moderately	Like Moderately	Like Moderately
6	Like Slightly	Like Slightly	Like Slightly	Like Slightly
5	Neither Like Nor Dislike	Neither Like Nor Dislike	Neither Like Nor Dislike	Neither Like Nor Dislike
4	Dislike Slightly	Dislike Slightly	Dislike Slightly	Dislike Slightly
3	Dislike Moderately	Dislike Moderately	Dislike Moderately	Dislike Moderately
2	Dislike Very Much	Dislike Very Much	Dislike Very Much	Dislike Very Much
1	Dislike Extremely	Dislike Extremely	Dislike Extremely	Dislike Extremely
	Comments	Comments	Comments	Comments

Directions: Completely encircle the category which best describes your reaction to the sample written above the column. Then under Comments give your reasons for rating the sample as you did. (i.e. Flavor too strong, odor not pleasant, too much seasoning, etc.).

Figure 4. Hedonic scale used to estimate the taste preference of foods by sensory method.

extremely). The judges were instructed to taste each sample and encircle the phrase which best described their feelings about the sample. Crackers and/or water were available between samples. Following judging, taste preference scores for each sample were added together and divided by the number of judges to give the final average score.

In the tables, three sets of figures are presented. They are as follows:

In taste preference scores, moldy fruit was discarded before being presented to the judges. The remainder was scored for taste acceptance, and the average scores were calculated.

In percentage survival, fruit was removed from cans. Total and non-moldy berries were counted, and the percentage of non-moldy edible fruit was calculated.

The adjusted preference score was obtained by multiplying the taste preference scores by the percent of the product that survived (percentage survival).

Adjusted preference scores give a more accurate picture of the true value of radiation. Taste preference scores by themselves do not give a complete picture, because they do not show the numbers of non-edible fruit; whereas, adjusted preference scores take this fact into consideration.

Studies were divided into two experiments:

Experiment I: Acceptability and refrigerated-life of gamma-irradiated strawberries.

Experiment II: Acceptability and refrigerated-life of gamma-irradiated sweet cherries.

RESULTS

Experiment Ia: Acceptability and refrigerated-life of gamma irradiated Shasta strawberries grown in Salinas Valley, California

For this experiment, Shasta strawberries grown in Salinas Valley, California, were shipped to Logan, Utah, and were irradiated within three days of harvest to 0 (control), 1, 2, and 3 x 10^5 rads. These berries, which were in good condition, were procured for use in exploratory work to determine procedures and methods to be used later on fruits locally grown.

After irradiation, these samples were stored at $40^{o}F$ and were evaluated by a panel of judges after two, seven, and nine days' storage.

Taste preference scores and adjusted preference scores for this part of the experiment are presented in Table 1 and Figure 5. Strawberries receiving the 1, 2, and 3 x 10^5 rads had similar adjusted preference scores after two days of storage. As the storage period lengthened, the berries at 3 x 10^5 rads scored highest. However, even the high adjusted preference score of five (neither like nor dislike) at nine days indicated that the berries were not high in taste acceptability.

Table 1. Effect of radiation dose on the taste preference and shelf life of Shasta strawberries stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

Days in storage	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
	Control	1	2	3	Control	1	2	3	Control	1	2	3
2	7.1	7.1	6.9	6.2	78	93	96	100	5.5	6.6	6.6	6.2
7	6.0	6.7	6.1	5.8	40	66	91	100	2.4	4.4	5.5	5.8
9	5.6	6.4	6.5	6.7	18	16	60	75	1.0	1.0	3.9	5.0

[a]Survival refers to non-moldy berries.

[b]Adjusted scores were secured by multiplying taste preference score by percent survival.

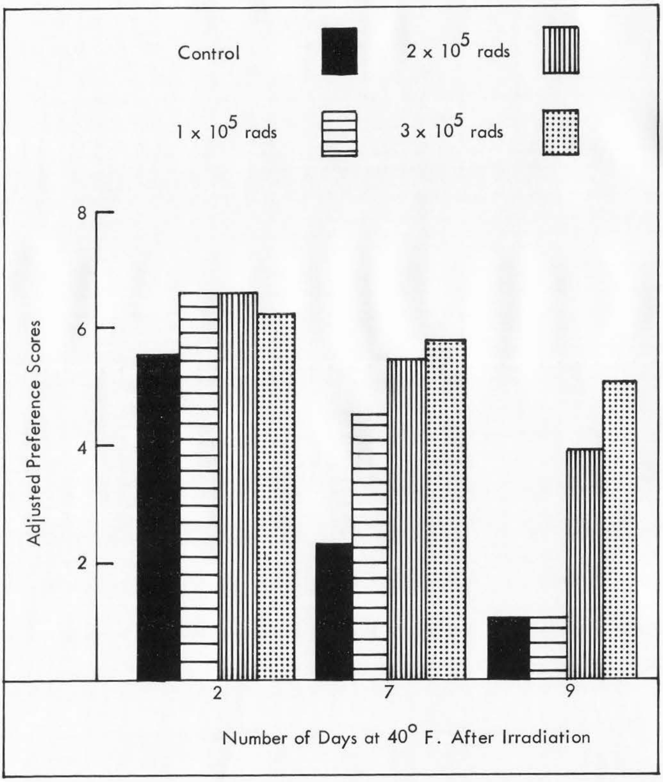

Figure 5. Effect of radiation dose on the adjusted preference score for Shasta strawberries stored at 40°F and evaluated after two, seven, and nine days.

During the extended storage period of nine days, there was a wide variation in physical characteristics of the berries. After two days of storage, berries were similar at all levels of irradiation--firm and bright red. As the storage period increased, the berries at control and 1×10^5 rads showed increasing mold growth and deterioration. The color remained fairly good during this time. The physical quality of the berries decreased during the storage period, but more rapidly at the lower (1×10^5 rads) levels of radiation (Figure 6).

Experiment Ib: Acceptability and refrigerated-life of six varieties of gamma-irradiated strawberries grown in Farmington, Utah

For this experiment, six varieties of strawberries--Kasuga, Lindalicious, Marshall, Robinson, Shasta, and Sparkle--were obtained from the Farmington Field Station and were irradiated to 0 (control), 1, 2, and 3×10^5 rads. Kasuga and Lindalicious were at the stage of excellent commercial ripeness; Marshall, Robinson, and Shasta were in fair-to-good commercial ripeness, slightly on the overripe side; while Sparkle was slightly dry, as a result of inadequate irrigation before harvest. The samples of strawberries were stored at $40^{\circ}F$ and were evaluated for mold growth and taste quality every fifth day, starting on the third day after irradiation and continuing for 25 days.

Three days' storage after irradiation.--According to Table 2, the taste preference scores and adjusted pref-

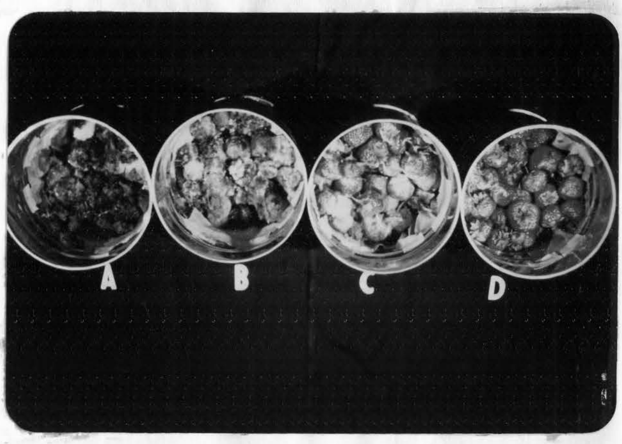

Figure 6. Effects of radiation dose on mold growth and ripening of Shasta strawberries; A = non-irradiated control; B = 1 x 10^5 rads; C = 2 x 10^5; D = 3 x 10^5.

Table 2. Effect of radiation dose on the taste preference and shelf life of strawberry varieties, evaluated three days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	1	2	3	Control	1	2	3	Control	1	2	3
Kasuga	6.3	6.3	6.0	5.1	99	99	98	100	6.2	6.2	5.9	5.1
Lindalicious	6.4	7.2	6.1	6.1	99	99	100	100	6.3	7.1	6.1	6.1
Marshall	5.7	5.5	5.7	4.2	100	100	100	100	5.7	5.5	5.7	4.2
Robinson	5.5	4.7	6.3	6.5	100	97	100	100	5.5	4.6	6.3	6.5
Shasta	5.9	5.4	5.5	6.1	98	100	100	100	5.7	5.4	5.5	6.1
Sparkle	7.7	7.7	6.9	7.0	100	100	100	100	7.7	7.7	6.9	7.0

[a]Survival refers to non-moldy berries.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

erence scores show ratings between 4.2 (dislike slightly) and 7.7 (like very much). In general, for both of these scores, all varieties rated highest at the 1 and 2 x 10^5 rad level. There were more low scores at 3 x 10^5 rads than at any other level, but differences were not significant. Sparkle received the highest scores at control and 1 x 10^5 rad for both taste preference and adjusted preference scores.

During the preparation of the strawberries for the taste panel, it was observed that the Marshall, Robinson, and Shasta were somewhat bleached at the higher dose of radiation. Light pink bruised spots were observed on the Lindalicious, Marshall, Robinson, Sparkle, and Shasta at 2 and 3 x 10^5 rads of radiation. At 3 x 10^5 rads, many of the berries in Marshall, Lindalicious, Sparkle and Shasta appeared to be soft and spongy.

Eight days' storage after irradiation.--It is evident from Table 3 that there was a wide variation in the scoring of all varieties of strawberries. For both taste preference scores and adjusted preference scores, the Sparkle at 1 x 10^5 rads received the highest scores for any variety. The lowest scores were given to the Marshall at 1 and 2 x 10^5 rads. The taste acceptability of the irradiated berries was better than that of the control for each variety.

Upon examination, Robinson, Shasta, and Marshall were somewhat bleached at 2 and 3 x 10^5 rads, while Linda-

Table 3. Effect of radiation dose on the taste preference and shelf life of strawberry varieties, evaluated eight days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	1	2	3	Control	1	2	3	Control	1	2	3
Kasuga	5.1	4.0	5.6	5.2	94	100	100	100	4.8	4.0	5.6	5.2
Lindalicious	5.7	7.3	5.4	5.2	96	97	100	100	5.5	7.1	5.4	5.2
Marshall	4.3	3.6	3.6	4.3	20	74	100	100	0.9	2.7	3.6	4.3
Robinson	5.4	4.4	6.5	6.2	100	100	100	100	5.4	4.4	6.5	6.2
Shasta	4.5	4.8	5.6	5.7	84	94	100	100	3.8	4.5	5.6	5.7
Sparkle	7.3	8.0	6.5	6.6	90	100	100	100	6.6	8.0	6.5	6.6

[a]Survival refers to non-moldy berries.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

licious was slightly bleached at these two higher doses of radiation. In the five-day period, there seemed to be an increase of light pink bruised spots in the Lindalicious, Marshall, Robinson, and Shasta at the 2 and 3 x 10^5 rads. A few light pink bruised spots were observed on the Sparkle at 2 and 3 x 10^5 rads. The Marshall appeared soft and overripe at the control and 1 x 10^5 rads, but was in poor condition at 2 and 3 x 10^5 rads. The rest of the berries appeared to be firm at the control and 1 x 10^5 rads; a few berries were soft at 2 x 10^5 rads, and some fruit became soft and spongy at the 3 x 10^5 rads. For the first time, it was noticed that the skins of the Lindalicious berries at 1, 2, and 3 x 10^5 rads seemed to be somewhat dry and seedy.

Thirteen days' storage after irradiation.--Table 4 shows that no one variety was definitely better than the others in taste acceptability after 13 days' storage. The Kasuga, Lindalicious, Marshall, and Robinson were scored highest at 1 x 10^5 rads in taste preference scores, but the adjusted preference scores for all varieties were highest at 2 or 3 x 10^5 rads. The Sparkle again scored slightly higher (of all varieties) for this 13-day storage period.

The Marshall, as a whole, was in poor condition. The control was for the most part unacceptable because of the mold growth and overripe berries, and those irradiated at 1, 2, and 3 x 10^5 rads were overripe with large areas

Table 4. Effect of radiation dose on the taste preference and shelf life of strawberry varieties, evaluated 13 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	1	2	3	Control	1	2	3	Control	1	2	3
Kasuga	3.8	5.6	5.6	4.0	85	84	99	100	3.2	4.7	5.5	4.0
Lindalicious	4.3	5.7	5.7	5.5	42	72	99	100	1.8	4.1	5.6	5.5
Marshall	4.3	5.1	4.3	4.5	24	25	91	100	1.0	1.3	3.9	4.5
Robinson	4.7	6.3	4.5	5.6	92	41	91	100	4.3	2.6	4.1	5.6
Shasta	4.7	4.8	4.8	5.7	43	36	89	100	2.0	1.7	4.3	5.7
Sparkle	6.1	6.5	6.2	6.6	55	74	89	96	3.4	4.8	5.5	6.3

[a]Survival refers to non-moldy berries.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

of bruised spots and soft texture. Sparkle, Shasta, and Lindalicious had varying degrees of soft berries in the control. At this level, the Robinson was fairly fresh looking with an occasional bruised spot, and was slightly softened. These berries seemed to look a little better at 1 and 2 x 10^5 rads. A few soft berries were in each variety, and almost every berry had a soft bruised spot. The Kasuga seemed to be the exception. At the control, 1, and 2 x 10^5 rads level, the berries were firm and bright red in color. At 3 x 10^5 rads all above-mentioned varieties from a few in the Sparkle to one-half of the berries in the Kasuga seemed to acquire the peculiar sponginess. The same berries--Marshall, Robinson, Lindalicious, and Shasta--that showed some bleaching at the 8-day storage period, exhibited the same characteristics after 13 days of storage.

Seventeen days' storage after irradiation.--According to Table 5, the scores varied widely in taste preference scores and adjusted preference scores for all varieties. It should be noted, that no scores were recorded for the Marshall at control, because the fruit was unacceptable due to spoilage. The highest scores for taste preference scores and adjusted preference scores were equally divided at 2 and 3 x 10^5 rads.

After 17 days of storage, all varieties were examined visually. During this storage period, the greatest change seemed to take place in the control group. The

Table 5. Effect of radiation dose on the taste preference and shelf life of strawberry varieties, evaluated 17 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	1	2	3	Control	1	2	3	Control	1	2	3
Kasuga	3.9	5.6	3.8	6.0	71	82	98	100	2.8	4.6	3.7	6.0
Lindalicious	4.0	3.8	5.3	3.2	31	60	94	100	1.2	2.3	5.0	3.2
Marshall	*	4.7	5.0	4.2	5	21	79	100	*	1.0	4.0	4.2
Robinson	2.9	3.6	5.5	4.4	44	91	59	100	1.3	3.3	3.2	4.4
Shasta	3.0	4.9	5.0	5.8	9	26	93	100	0.3	1.3	4.6	5.8
Sparkle	4.6	6.0	6.6	5.9	52	70	94	98	2.4	4.2	6.2	5.8

[a]Survival refers to non-moldy berries.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

*Berries were unacceptable because of mold growth.

Marshall was unacceptable because of spoilage. It was noticed that the Sparkle, Shasta, and Lindalicious were fairly dark red in color yet had an aged and stale appearance. From 10 to 50 percent of the berries were soft in these varieties. The Robinson and Kasuga seemed to be fairly firm, bright red, and fresh. At 1 and 2 x 10^5 rads these berries were very little changed from eight-day storage period. Color was somewhat deepened. Some berries were a little dried-appearing, and some had dark red dried spots. The Marshall was dark red and soft. Texture of Lindalicious skin seemed to be more seedy at these doses of irradiation. The typical spongy texture was observed in some berries of all varieties at the 3 x 10^5 rads.

Twenty-three days' storage after irradiation.--It can be seen from Table 6 that all varieties at control were unacceptable for judging because of spoilage. In the taste preference scores, no one dose of irradiation was superior to the other, since high scores were equally distributed at all levels of irradiation. The data presented for the adjusted preference scores shows that only two varieties--Kasuga and Sparkle--scored as high as "like slightly" for the 2 and 3 x 10^5 rads. The other varieties were disliked either slightly or moderately. Thus, the higher doses of irradiation helped to prevent spoilage and therefore preserved the taste.

The control group in all varieties was unacceptable because of spoilage due to mold growth. In four of the

Table 6. Effect of radiation dose on the taste preference and shelf life of strawberry varieties evaluated 23 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	1	2	3	Control	1	2	3	Control	1	2	3
Kasuga	*	3.2	5.0	5.9	0	17	86	97	*	0.5	4.3	5.7
Lindalicious	*	3.1	4.6	4.3	0	21	78	89	*	0.7	3.6	3.8
Marshall	*	5.6	4.9	5.5	0	25	56	89	*	1.4	2.7	4.9
Robinson	*	3.4	4.1	4.3	0	57	72	100	*	1.9	3.0	4.3
Shasta	*	4.1	3.8	4.1	0	9	69	94	*	0.4	2.6	3.8
Sparkle	*	6.1	6.1	5.7	0	49	93	98	*	3.0	5.7	5.6

[a]Survival refers to non-moldy berries.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

*Berries were unacceptable because of mold growth.

varieties--Kasuga, Lindalicious, Marshall, and Shasta, 30 to 60 percent of the berries were unacceptable because of mold spoilage at 1 x 10^5 rads. All of these varieties were characterized by medium dark red color, soft spots, and blemishes on every berry. Marshall and Lindalicious appeared to be somewhat dried and over-mature. Robinson and Sparkle seemed to be in better condition. They were medium red in color and somewhat withered with one or two soft berries.

It was noticed that there was a wide range of varietal differences at the 2 x 10^5 rads of irradiation. Marshall and Robinson were in poor condition. Shasta was slightly better with most berries having some soft spots and one-third of the berries bruised badly. Lindalicious, Sparkle, and Kasuga maintained a reasonably good appearance--somewhat firm but dried. There were no more than four or five soft berries in each of these three varieties. Lindalicious showed the same seedy, tough skin that became evident after eight days of storage.

For the most part at 3 x 10^5 rads, all varieties seemed to be similar to those irradiated at 2 x 10^5 rads. The difference most evident seemed to be in a greater number of soft berries. The spongy texture of these soft berries again showed up at the highest dose of irradiation as it did in the three previous storage periods. Marshall, Robinson, Lindalicious, and Shasta showed the same characteristic bleaching as was noted at the higher (2 and 3 x 10^5 rads) doses of irradiation.

Twenty-eight days' storage after irradiation.--The value of irradiation becomes increasingly apparent from information shown in Table 7. The controls in all varieties were unacceptable because of spoilage. This was also true for the Marshall berries at the 1 x 10^5 rads. High scores for the taste preference scores during this period were equally divided between 2 and 3 x 10^5 rads. The trend which was established at the last storage period for adjusted taste preference scores continued at this time. High scores were at the 3 x 10^5 rad level for all varieties with only the Sparkle rating slightly acceptable.

There seemed to be a wide variation in most of the berries when examined after 28 days of storage. The berries at control and 1 x 10^5 rads in all varieties were, in general, unacceptable. At 2 and 3 x 10^5 rads the Sparkle was in fairly good condition. Almost every berry had some light surface mold. Most every variety irradiated at 2 and 3 x 10^5 rads was characterized by soft spots on each berry. A few more berries at 3 x 10^5 rads had the spongy texture that seemed to be so typical of this dose. The bleaching that had appeared at other storage periods was also noted at this time. At 2 and 3 x 10^5 rads, the skin of the Lindalicious appeared to be tough and seedy as previously mentioned.

Figures 7 through 12 indicate that the adjusted

Table 7. Effect of radiation dose on the taste preference and shelf life of strawberry varieties, evaluated 28 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	1	2	3	Control	1	2	3	Control	1	2	3
Kasuga	*	3.1	3.7	4.8	0	14	74	90	*	0.4	2.7	4.3
Lindalicious	*	4.0	3.9	4.6	0	19	33	78	*	0.8	1.3	3.6
Marshall	*	*	5.4	4.6	0	0	13	77	*	*	0.7	3.5
Robinson	*	3.7	4.2	4.4	0	30	74	85	*	1.1	3.1	3.7
Shasta	*	3.4	4.1	3.9	0	10	49	95	*	0.3	2.0	3.7
Sparkle	*	6.1	6.7	5.9	0	26	85	76	*	1.6	5.7	5.7

[a]Survival refers to non-moldy berries.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

*Berries were unacceptable because of mold growth.

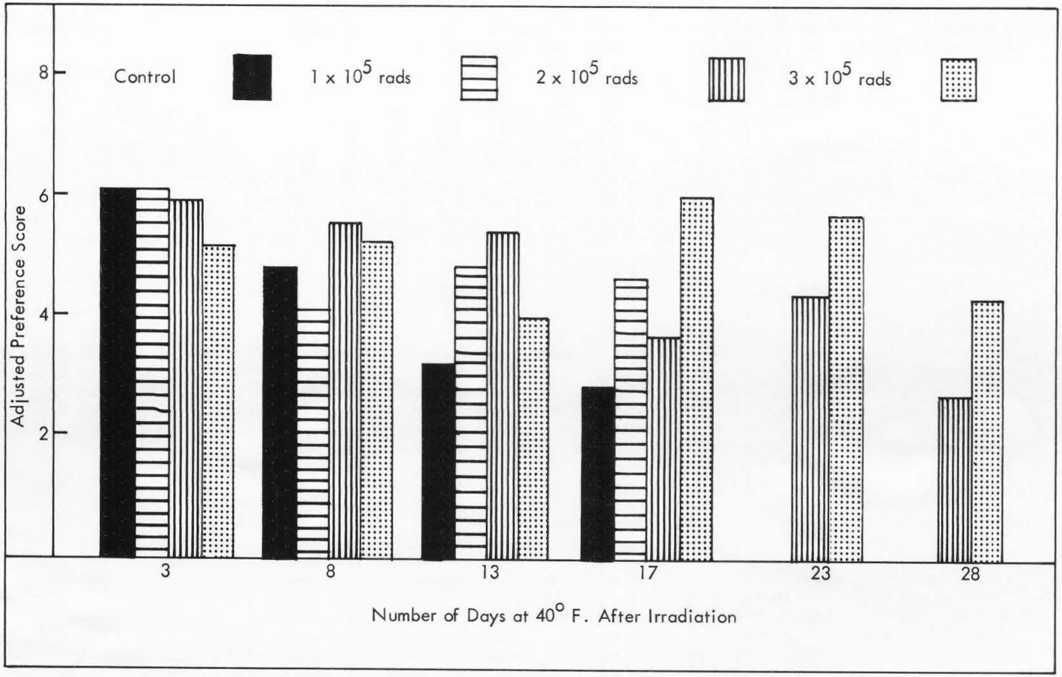

Figure 7. Effect of radiation dose on the adjusted preference score for Kasuga strawberries stored at 40°F and evaluated after 3, 8, 13, 17, 23, and 28 days.

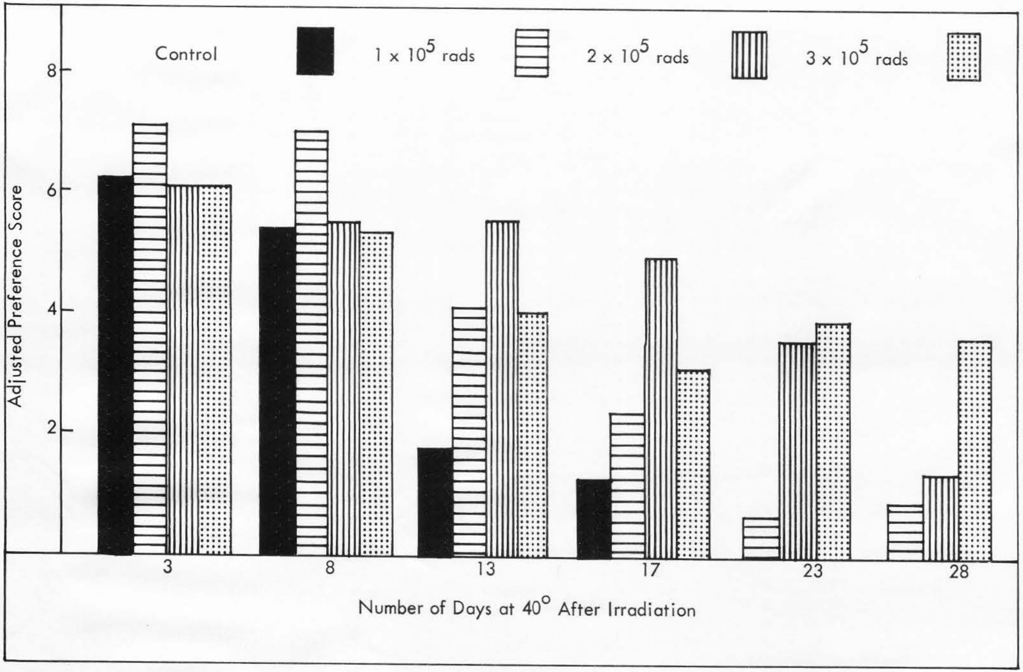

Figure 8. Effect of radiation dose on the adjusted preference score for Lindalicious strawberries stored at 40°F and evaluated after 3, 8, 13, 17, 23, and 28 days.

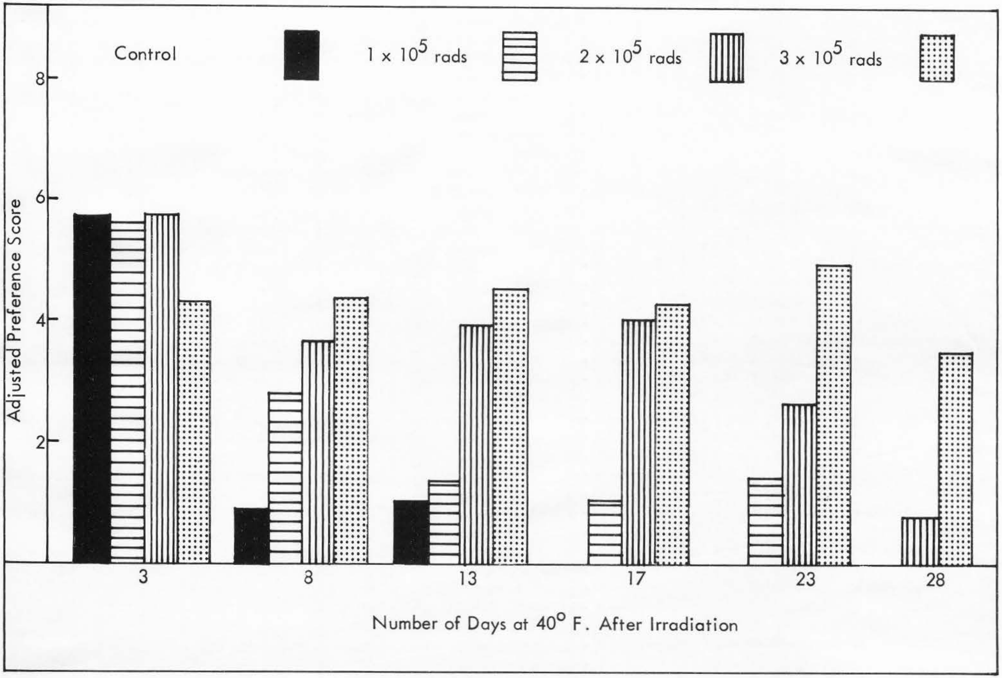

Figure 9. Effect of radiation dose on the adjusted preference score for Marshall strawberries stored at 40°F and evaluated after 3, 8, 13, 17, 23, and 28 days.

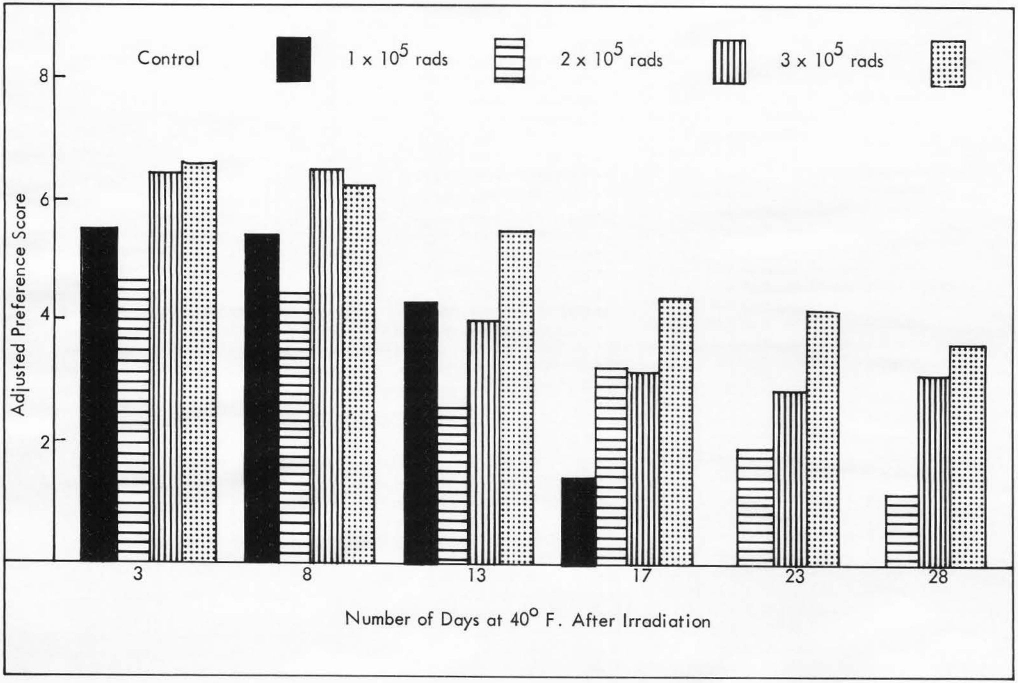

Figure 10. Effect of radiation dose on the adjusted preference score for Robinson strawberries stored at 40°F and evaluated after 3, 8, 13, 17, 23, and 28 days.

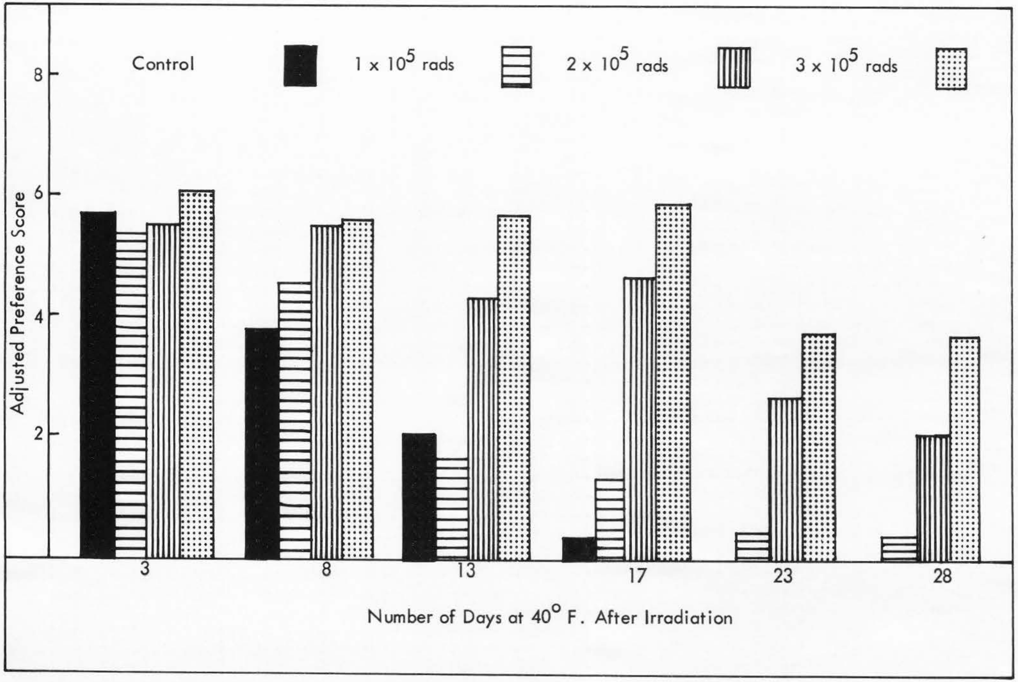

Figure 11. Effect of radiation dose on the adjusted preference score for Shasta strawberries stored at 40°F and evaluated 3, 8, 13, 17, 23, and 28 days.

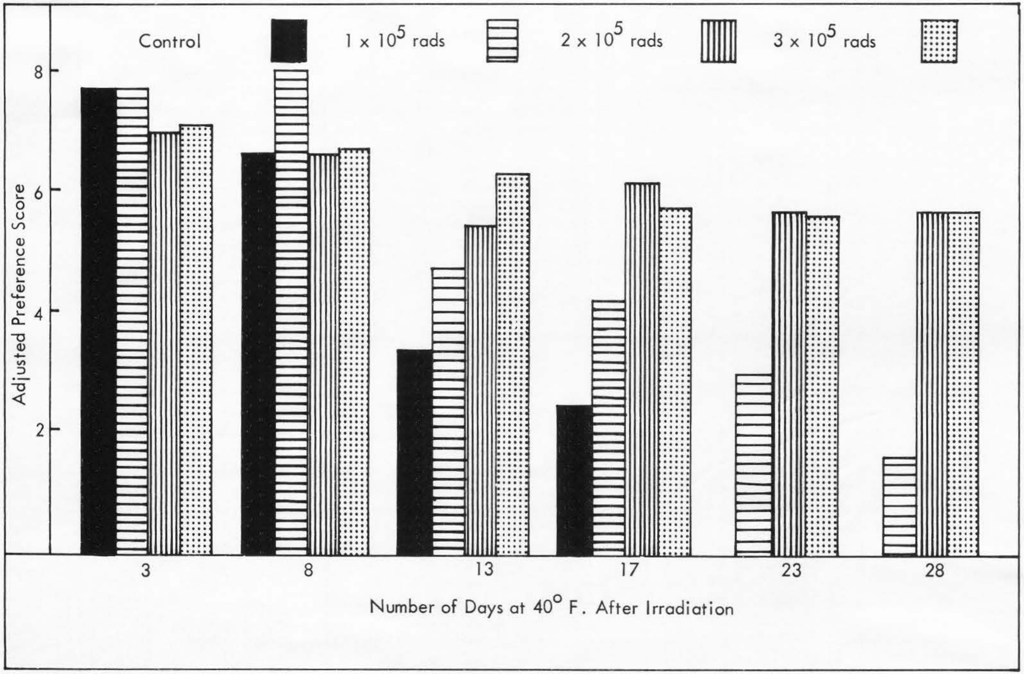

Figure 12. Effect of radiation dose on the adjusted preference score for Sparkle strawberries stored at 40°F and evaluated after 3, 8, 13, 17, 23, and 28 days.

preference scores of all the varieties studied declined progressively as the storage period advanced, regardless of the radiation doses. However, the scores at the 3 x 10^5 rads declined less rapidly than those of the control. From the 13-day storage period, high scores were recorded at 2 and 3 x 10^5 rads (with the greatest number of high scores at 3 x 10^5 rads level). Except for the first two storage periods, the adjusted preference scores appeared to be directly related to the radiation dose, i.e., as the radiation dose advanced from 1 x 10^5 rads, the overall adjusted scores increased.

Experiment Ic: Acceptability and refrigerated-life of partially green gamma-irradiated strawberries grown in Farmington, Utah

This experiment was conducted to determine if partially-green strawberries would be better for irradiation than commercially ripe strawberries.

Shasta strawberries were picked when they were partially green. They were irradiated at 0 (control), 1, 2, and 3 x 10^5 rads. After 15 days of storage at 40^oF and 2 days at room temperature, taste testing scores were recorded. From the information shown in Table 8 and Figure 13, it is evident that the berries were unacceptable in taste quality. High score was 3.7 (dislike moderately) at 2 x 10^5 rads in the taste preference scores. In adjusted preference scores 2 and 3 x 10^5 rads were the highest with a score of 3.4 and 3.3 (dislike moderately), re-

Table 8. Effect of radiation dose on the taste preference, and shelf life of Shasta strawberries picked green, stored at 40°F for 15 days, then stored for 2 days at room temperature. Evaluation was taken 17 days after irradiation (preference scores of tasted fruit percentage survival[a] and adjusted[b] preference scores)

Dose x 10^5 rads	Taste preference scores	Percentage survival	Adjusted preference scores
Control	2.9	44	1.3
1	3.5	89	2.1
2	3.7	93	3.4
3	3.3	100	3.3

[a]Survival refers to non-moldy berries.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

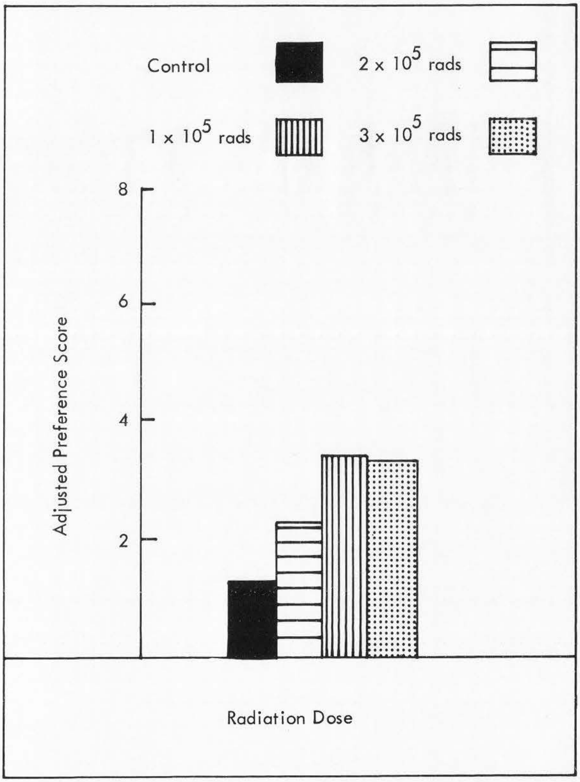

Figure 13. Effect of radiation dose on the adjusted preference score for partially green strawberries stored at 40°F and evaluated 17 days after irradiation.

spectively. The low scores were indicative of a lack of flavor development. However, flavor seemed to be improved in varying degrees by irradiation. There was a wide variation in color. Control ranged from medium dark red to yellow red. Some brown spoiled spots seemed to be present. As dosage increased, berries looked more immature and underripe. Soft spots decreased with increase in radiation, except at 3×10^5 rads where 25 percent of the berries, which had a grayish cast, were soft and spongy.

Experiment II: Acceptability and refrigerated-life of gamma-irradiated sweet cherries grown in Pleasant View, Utah

Four varieties of sweet cherries--Bing, Lambert, Napoleon, and Windsor, were irradiated at 0 (control), 2, 3, and 4×10^5 rads. Napoleon and Windsor were at the stage of good commercial ripeness; Lambert was slightly underripe, while Bing was on the overripe side. The cherries were stored at 40^oF and were evaluated for taste quality every seventh day starting one week after irradiation. Mold growth and mold classification were determined at the time the cans containing the fruit were opened.

Eight days' storage after irradiation.--According to the information shown in Table 9, generally speaking, all varieties were scored highest at 2 and 3×10^5 rads for both taste preference and adjusted preference scores. The highest scores for this storage period and also for

Table 9. Effect of radiation dose on the taste preference and shelf life of sweet cherry varieties evaluated eight days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	2	3	4	Control	2	3	4	Control	2	3	4
Bing	7.9	8.5	7.9	7.4	94	97	100	100	7.4	8.2	7.9	7.4
Lambert	7.9	8.2	8.5	7.2	95	100	100	100	7.5	8.2	7.5	7.2
Napoleon	7.0	7.6	7.7	7.7	99	99	100	100	6.9	7.5	7.7	7.7
Windsor	7.5	7.5	7.7	7.5	99	100	100	100	7.3	7.5	7.7	7.5

[a] Survival refers to non-moldy cherries.

[b] Adjusted scores were secured by multiplying taste preference scores by percent survival.

the entire experiment were 8.2 and 8.5 (like very much) which were received by the Bing and Lambert varieties at 2×10^5 rads in taste and adjusted preference scores.

After visual examination of Bing, Lambert, and Windsor varieties, it seemed that there was very little difference in color at control, 2, 3, and 4×10^5 rads. Napoleon seemed to bruise more readily and Bing showed somewhat more softening around the stem end.

Fifteen days' storage after irradiation.--From Table 10 it can be noticed that all scores dropped somewhat from the previous storage period. Each of the varieties scored highest at a different dose of irradiation for both taste preference scores and adjusted preference scores. Highest score 8.0 (like very much) for all varieties for the fifteenth day of storage after radiation was received by Bing for controls in taste preference scores and 7.6 (like very much) at 3×10^5 rads for adjusted preference scores.

In the Lambert, Bing, and Windsor varieties, the control was darkest in color, as a result of normal sweet cherry ripening. At the 2, 3, and 4×10^5 rads from 50 to 60 percent of the cherries were lighter in color. This lighter color was nearly the same as the color of the fruit at the beginning of the storage. The higher doses of radiation retarded the rate of ripening. All three of these varieties showed some softening at the higher doses of radiation. In the Bing, softening around the stem end

Table 10. Effect of radiation dose on the taste preference and shelf life of sweet cherry varieties, evaluated 15 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	2	3	4	Control	2	3	4	Control	2	3	4
Bing	8.0	7.6	7.8	7.4	87	94	97	100	7.0	7.1	7.6	7.4
Lambert	7.3	6.7	5.7	6.3	91	96	96	100	6.6	6.4	5.5	6.3
Napoleon	7.2	6.9	6.8	7.1	93	97	100	100	6.7	6.7	6.8	7.1
Windsor	6.3	6.5	6.3	5.9	90	98	98	100	5.7	6.4	6.2	5.9

[a]Survival refers to non-moldy cherries.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

was noticed to be present at this storage period. The appearance of the Napoleon was similar at both the 8-day and 15-day storage periods, except there were more bruised spots.

Twenty-two days' storage after irradiation.--Table 11 shows that the highest scores for the taste preference and adjusted preference scores for all varieties were, generally, at 3 and 4 x 10^5 rads. Bing received highest score of 7.7 (like very much) at 4 x 10^5 rads for this storage period for taste preference and adjusted preference scores. It should be noticed that from the fifteenth day of storage to this storage period, the majority of scores remained the same or were lowered. However, those scores that raised were, in general, from the higher (3 and 4 x 10^5 rads) doses of irradiation.

At this storage period, at least 75 percent of the cherries of all varieties at control were deeper in color. Bing showed some softening at the stem; Lambert was firm; Napoleon was firm with a few bruised spots; and Windsor exhibited signs of becoming soft. The appearance and physical characteristics of cherries at 2, 3, and 4 x 10^5 rads were similar to those at the fifteenth day of storage. The exception was Napoleon at 2, 3, and 4 x 10^5 rads which was deeper in color. Those cherries at 2 and 3 x 10^5 rads exhibited more and larger bruised spots.

Twenty-nine days' storage after irradiation.--According to Table 12, in general, all scores were lower

Table 11. Effect of radiation dose on the taste preference and shelf life of sweet cherry varieties, evaluated 22 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	2	3	4	Control	2	3	4	Control	2	3	4
Bing	7.5	7.6	7.2	7.7	76	90	97	100	5.7	6.8	7.0	7.7
Lambert	7.3	7.1	6.2	5.8	82	94	99	98	6.0	6.7	6.1	5.7
Napoleon	7.1	6.9	6.8	7.3	84	88	96	100	6.0	6.0	6.5	7.2
Windsor	6.3	5.9	6.6	6.3	93	96	100	100	5.8	5.7	6.6	6.3

[a]Survival refers to non-moldy cherries.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

Table 12. Effect of radiation dose on the taste preference and shelf life of sweet cherry varieties, evaluated 29 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	2	3	4	Control	2	3	4	Control	2	3	4
Bing	8.2	7.4	6.7	7.1	68	82	93	99	5.6	6.1	6.2	7.0
Lambert	7.4	6.8	6.7	6.7	80	88	93	96	5.9	6.0	6.2	6.4
Napoleon	6.6	6.3	5.9	6.6	88	89	92	96	5.8	5.6	5.4	6.3
Windsor	6.1	6.0	6.7	6.3	92	94	98	99	5.6	5.6	6.6	6.2

[a]Survival refers to non-moldy cherries.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

than those of the twenty-second day of storage, except at 3 and 4 x 10^5 rads for Lambert variety. Taste preference scores for Bing and Lambert decreased with increased radiation, while adjusted preference scores increased with increased radiation for all varieties. Bing, Lambert, and Napoleon were scored highest at 4 x 10^5 rads, while Windsor was scored highest at 3 x 10^5 rads for adjusted preference scores.

Bing, Lambert, and Windsor exhibited the same characteristics at control as at the previous storage period, except they were a dark red. Cherries of these varieties at 2, 3, and 4 x 10^5 rads were more immature appearing than those at control. Lambert and Windsor were medium bright red. Bing was slightly darker. Lambert and Bing cherries became somewhat softer in texture with increased radiation, while Windsor cherries became firmer. Napoleon, which was riper-appearing, but firm at the control, had a blemish or bruise on most cherries; whereas, with increase in radiation, cherries became somewhat deeper in color and were more subject to bruising.

Thirty-six days' storage after irradiation.--It is evident from Table 13 that the scores at control and 2 x 10^5 rads, in general, decreased from the last storage period. Adjusted preference scores at 3 and 4 x 10^5 rads decreased, and all varieties of cherries except Windsor were liked moderately or slightly (6.0 to 6.8). Scores that were given to Windsor were considerably lower than

Table 13. Effect of radiation dose on the taste preference and shelf life of sweet cherry varieties, evaluated 36 days after irradiation, stored at 40^{o}F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	2	3	4	Control	2	3	4	Control	2	3	4
Bing	6.4	7.1	7.7	7.3	34	69	82	93	2.2	4.9	6.3	6.8
Lambert	6.2	6.5	6.3	6.3	58	85	96	98	3.6	5.5	6.0	6.2
Napoleon	7.2	7.2	6.9	6.4	71	84	95	97	5.1	6.0	6.6	6.2
Windsor	5.4	5.4	5.1	5.5	79	84	96	99	4.3	4.5	4.9	5.4

[a]Survival refers to non-moldy cherries.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

for any other variety. Seventy-five percent of all low scores were present at controls. Lowest score was 2.2 (dislike very much) at control for Bing. This was a substantial decrease from preceding storage periods.

As a whole, cherries of Bing, Lambert, and Windsor varieties were in good condition. They showed very slight physical changes except for normal cherry ripening. Fruit which was fairly firm at 2, 3, and 4×10^5 rads became lighter in color and more immature-appearing as the dose increased. In Windsor variety, a few bruises appeared at these levels of irradiation. Radiation seemed to cause some shriveling and softening at the stem in Bing. At this time, it was noticed that as the radiation dose advanced from 0 to 4×10^5 rads, the flesh of the cherry of these three varieties became increasingly lighter in color (Figure 14). Napoleon was more mature-appearing with an increase in number and degree of bruised fruit at the control. Cherries at 2, 3, and 4×10^5 rads were progressively deeper in color with a number of fairly large bruises. At the 4×10^5 rad level a few cherries were unacceptable because of bruising.

Forty-three days' storage after irradiation.--From Table 14 it will be noted that the high scores for adjusted preference scores for Bing and Lambert were at 4×10^5 rads; for Napoleon, at control at 4×10^5 rads; and for Windsor, at 3×10^5 rads. Lowest score again was 2.2 (dislike very much) at control for Bing for adjusted pref-

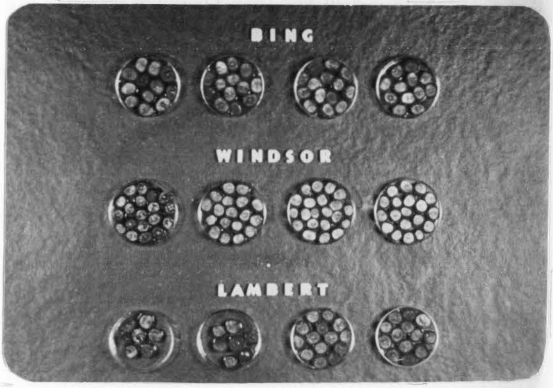

Figure 14. Effect of radiation dose on the flesh color of Lambert, Windsor, and Bing cherries (36th day of storage). 1 = non-irradiated control; 2 = 2×10^5 rads; 3 = 3×10^5 rads; 4 = 4×10^5 rads.

Table 14. Effect of radiation dose on the taste preference and shelf life of sweet cherry varieties, evaluated 43 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	2	3	4	Control	2	3	4	Control	2	3	4
Bing	7.1	6.8	6.1	6.6	31	55	86	97	2.2	3.7	5.2	6.4
Lambert	7.0	6.8	6.2	7.2	59	74	93	94	4.1	5.0	5.8	6.8
Napoleon	6.6	5.7	5.9	6.2	75	75	83	80	5.0	4.3	4.7	5.0
Windsor	5.8	5.3	6.4	5.5	64	74	92	95	3.7	3.9	5.9	5.2

[a]Survival refers to cherries not affected by mold and/or bacteria rot.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

erence score. More low scores were at control for adjusted preference scores than at any other level. Scores as a whole were only slightly lower than those from thirty-sixth day storage.

In preparing the fruit for judging it became evident that Bing, Lambert, and Windsor varieties of cherries showed slight physical changes except for normal cherry ripening. Cherries at control were deep red, but with increase in radiation, color became progressively lighter. Irradiated cherries at 2, 3, and 4×10^5 rads were brighter, and fresher-appearing than the fruit at control. Bruising and shriveling around the stem were more apparent in irradiated Bing cherries than in the control; however, there was less shriveling at 4×10^5 rads. Napoleon, at control, was very firm although most cherries were covered with small bruises. At the 2 and 3×10^5 rads level, the fruit which was in better condition than control had a few bruises and was fresh appearing. Cherries at the 4×10^5 rads were similar to those at 3×10^5 rads except some cherries had a soft, brown, spongy texture which was very similar to strawberries at the 3×10^5 rads level.

<u>Fifty days' storage after irradiation</u>.--High scores were 7.2 (like moderately) at 3×10^5 rads for Bing and 2×10^5 rads for Napoleon in taste preference scores (Table 15). In adjusted preference scores Bing was rated highest at 4×10^5 rads with a score of 5.6 (like slightly), while low score was 0.3 (dislike extremely) at 2×10^5 rads

Table 15. Effect of radiation dose on the taste preference and shelf life of sweet cherry varieties, evaluated 50 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	2	3	4	Control	2	3	4	Control	2	3	4
Bing	7.0	6.8	7.2	6.6	23	34	72	85	1.6	2.3	5.1	5.6
Lambert	6.2	5.5	5.5	6.2	38	39	80	85	2.4	2.1	4.4	5.3
Napoleon	6.5	7.2	5.9	6.4	64	70	67	50	4.2	5.0	4.0	3.2
Windsor	5.2	4.5	5.0	5.3	60	7	68	97	3.1	0.3	3.4	5.1

[a]Survival refers to cherries not affected by mold and/or bacteria rot.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

for Windsor. Adjusted preference scores were considerably lower than the scores of the previous storage, especially at control and 2×10^5 rads level. All varieties rated highest at the 3 and 4×10^5 rads level, except the Napoleon which rated highest at 2×10^5 rads.

Examination of the cherries of the three varieties--Bing, Lambert, and Windsor--revealed that they were very similar to those of the forty-third day of storage at most levels of radiation. Bing at the 4×10^5 rads showed more shriveling at the stem than the foregoing storage periods. Windsor cherries were mostly unacceptable at 2×10^5 rads level on the fiftieth day of storage. Napoleon cherries were very similar to the preceding storage period. A brown discoloration which seemed to be caused by radiation rather than bruising became apparent on the cherries irradiated at 2, 3, and 4×10^5 rads level. Because of this brown discoloration and the number of cherries which were bruised, fruit at 2×10^5 rads was in poor condition.

<u>Fifty-seven days' storage after irradiation</u>.--Table 16 shows that a definite trend was established which extended to the end of the experiment. High scores for Bing and Lambert were predominantly at 4×10^5 rads both for taste preference and adjusted preference scores, while those for Napoleon and Windsor remained at the control. No scores were recorded for Bing at control, and for Lambert and Windsor at 2×10^5 rads, because the fruit was unacceptable due to spoilage (Figure 15). Bing received

Table 16. Effect of radiation dose on the taste preference and shelf life of sweet cherry varieties, evaluated 57 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	2	3	4	Control	2	3	4	Control	2	3	4
Bing	*	6.8	6.9	6.5	0	30	73	79	*	2.0	5.0	5.1
Lambert	6.4	*	6.6	6.7	29	3	37	64	1.9	*	2.4	4.3
Napoleon	6.5	5.5	5.9	6.0	75	64	69	68	4.9	3.5	4.1	4.1
Windsor	4.7	*	4.0	4.0	78	3	54	80	3.7	*	2.2	3.2

[a]Survival refers to cherries not affected by mold and/or bacteria rot.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

*Cherries were unacceptable because of mold growth and/or bacteria rot.

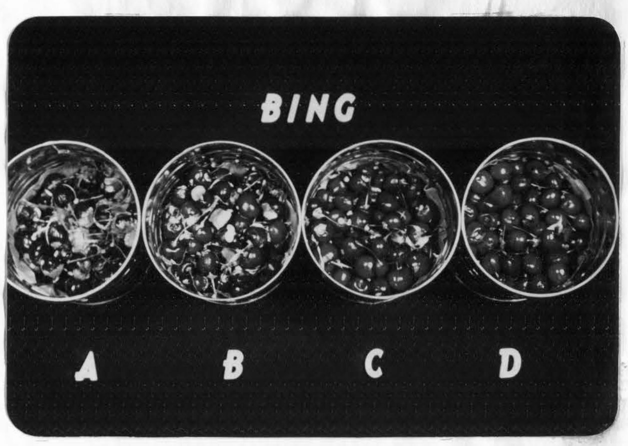

Figure 15. Effect of radiation dose and mold growth on ripening of Bing cherries (57th day of storage). 1 = non-irradiated control; 2 = 2 x 10^5 rads; 3 = 3 x 10^5 rads; 4 = 4 x 10^5 rads.

the highest scores at 3×10^5 rads of 6.9 (like moderately) and at 4×10^5 rads of 5.1 (neither like nor dislike) for taste preference and adjusted preference scores, respectively.

During the preparation of the cherries for judging, it was observed that Bing at control and Lambert and Windsor at 2×10^5 rads were unacceptable. These latter two varieties at control were dark red and mostly free from bruises. Cherries at 3 and 4×10^5 rads level of these two varieties were progressively lighter in color, fairly firm in texture, free from bruises, and fresh appearing. As the radiation dose increased from 2 to 4×10^5 rads, Bing cherries were more firm and fresh appearing, lighter in color and less bruised and shriveled.

Sixty-four days' storage after irradiation.--Adjusted preference scores as shown in Table 17 rated "5" (neither like nor dislike) or below for all varieties. When the unacceptable cherries were not considered, all taste preference scores were acceptable. No scores were recorded at control and 2×10^5 rads for Bing, and at 2×10^5 rads for Lambert and Windsor.

In appearance Bing cherries at 3 and 4×10^5 rads were characterized by considerable shriveling, and were medium red in color. Lambert and Windsor were dark red at control and fairly free from bruises. In both of these varieties, fruit was unacceptable at 2×10^5 rads, and Lambert was also unacceptable at 3×10^5 rads. Cherries

Table 17. Effect of radiation dose on the taste preference and shelf life of sweet cherry varieties, evaluated 64 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	2	3	4	Control	2	3	4	Control	2	3	4
Bing	*	*	7.4	6.3	0	0	52	84	*	*	3.8	5.3
Lambert	5.7	*	5.8	6.1	27	9	39	37	1.5	*	2.3	2.3
Napoleon	6.3	5.1	4.2	4.3	57	57	48	38	3.6	2.9	2.0	1.6
Windsor	5.1	*	3.9	4.6	78	2	40	87	4.0	*	1.6	4.0

[a] Survival refers to cherries not affected by mold and/or bacteria rot.

[b] Adjusted scores were secured by multiplying taste preference scores by percent survival.

* Cherries were unacceptable because of mold growth and/or bacteria rot.

in both varieties at 4×10^5 rads were in surprisingly good condition considering the length of the storage period. Napoleon cherries, as a whole, were very similar to preceding storage period, except the brown discoloration had spread over a wider area of the cherry at the 2×10^5 rad level.

Seventy-one days' storage after irradiation.--Table 18 indicates that no scores were recorded at control and 2×10^5 rads for Bing; at any level for Lambert; and at 2×10^5 rads for Windsor. High scores followed the same trend set in the preceding storage period for both taste preference and adjusted preference scores.

Bing cherries at 3×10^5 rads which were medium dark red in color with some shriveling were in surprisingly good condition and fairly fresh appearing. However, the 4×10^5 rads level did not keep as well. The cherries were lighter in color and were more shriveled. Windsor at control and all levels of treatment was similar to the previous storage period. Napoleon also was similar to the previous storage period except that at 2×10^5 rads almost every cherry was completely discolored by brownness so peculiar to this dose and this variety.

From Figures 16 through 18 it will be noted that the adjusted preference scores for these varieties declined progressively as the storage period advanced, regardless of radiation dose. Scores for Bing and Lambert cherries irradiated at 3 and 4×10^5 rads levels declined

Table 18. Effect of radiation dose on the taste preference and shelf life of sweet cherry varieties, evaluated 71 days after irradiation, stored at 40°F (preference scores of tasted fruits, percentage survival[a], and adjusted[b] preference scores)

	Taste preference scores Dose x 10^5 rads				Percentage survival Dose x 10^5 rads				Adjusted preference scores Dose x 10^5 rads			
Varieties	Control	2	3	4	Control	2	3	4	Control	2	3	4
Bing	*	*	5.6	4.8	0	0	31	58	*	*	1.7	2.8
Lambert	*	*	*	*	20	0	9	8	*	*	*	*
Napoleon	5.0	4.3	4.8	5.5	56	35	59	35	2.8	1.5	2.8	1.9
Windsor	4.2	*	3.6	3.6	84	0	30	45	3.5	*	1.1	1.6

[a]Survival refers to cherries not affected by mold and/or bacteria rot.

[b]Adjusted scores were secured by multiplying taste preference scores by percent survival.

*Cherries were unacceptable because of mold growth and/or bacteria rot.

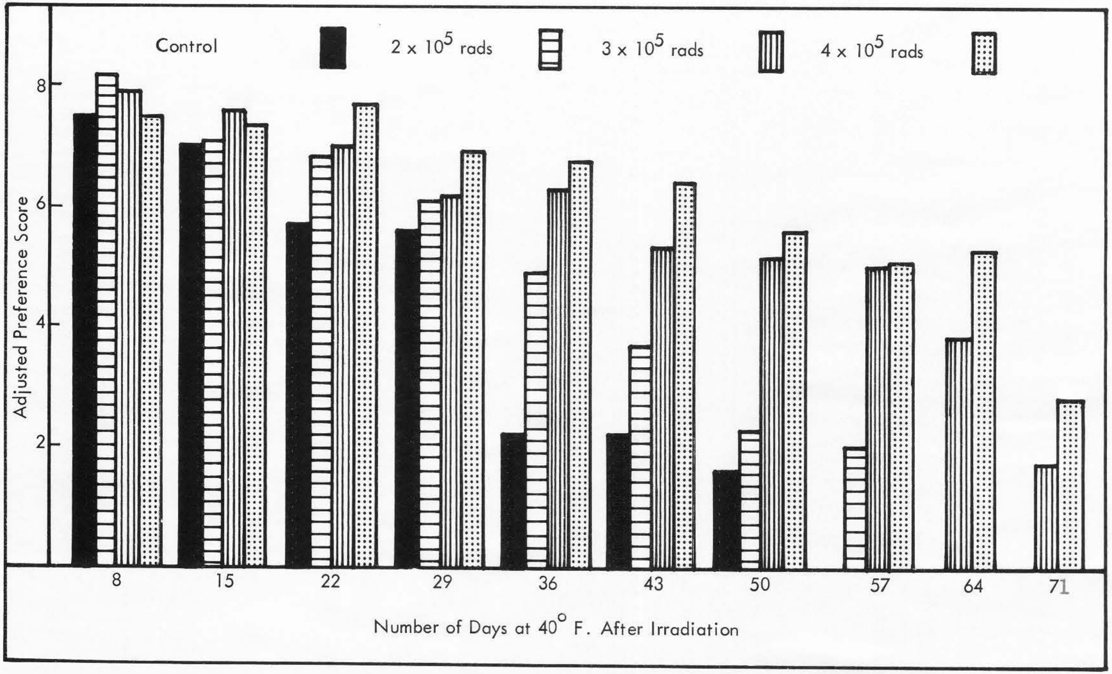

Figure 16. Effect of radiation dose on the adjusted preference score for Bing sweet cherries stored at 40°F and evaluated after 8, 15, 22, 29, 36, 43, 50, 57, 64, and 71 days.

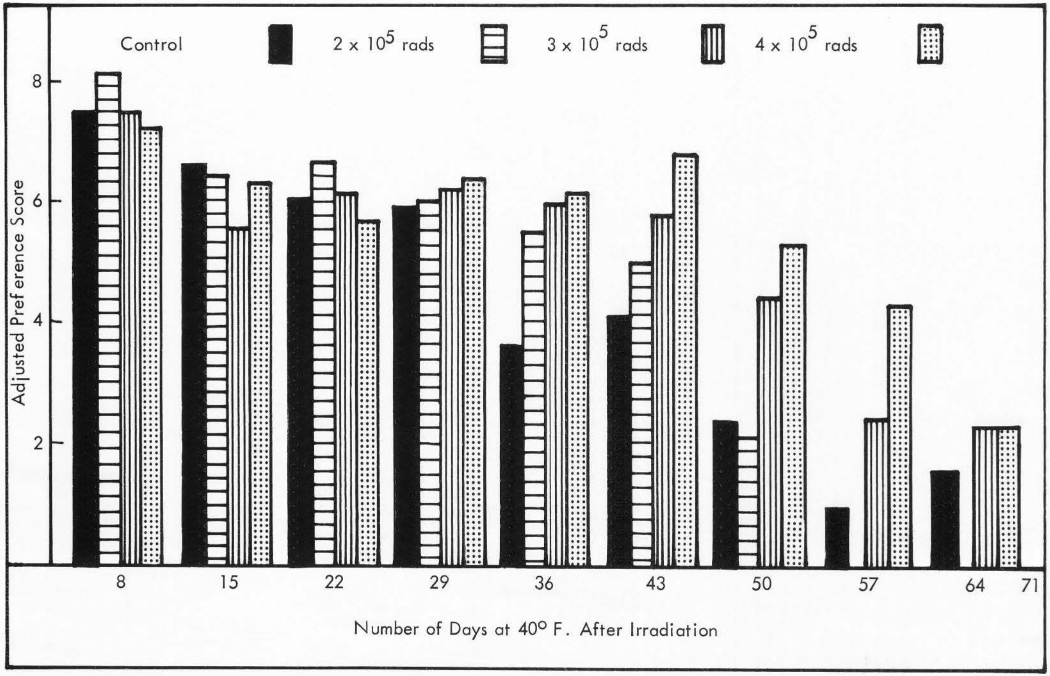

Figure 17. Effect of radiation dose on the adjusted preference score for Lambert sweet cherries stored at 40°F and evaluated after 8, 15, 22, 29, 36, 43, 50, 57, 64, and 71 days.

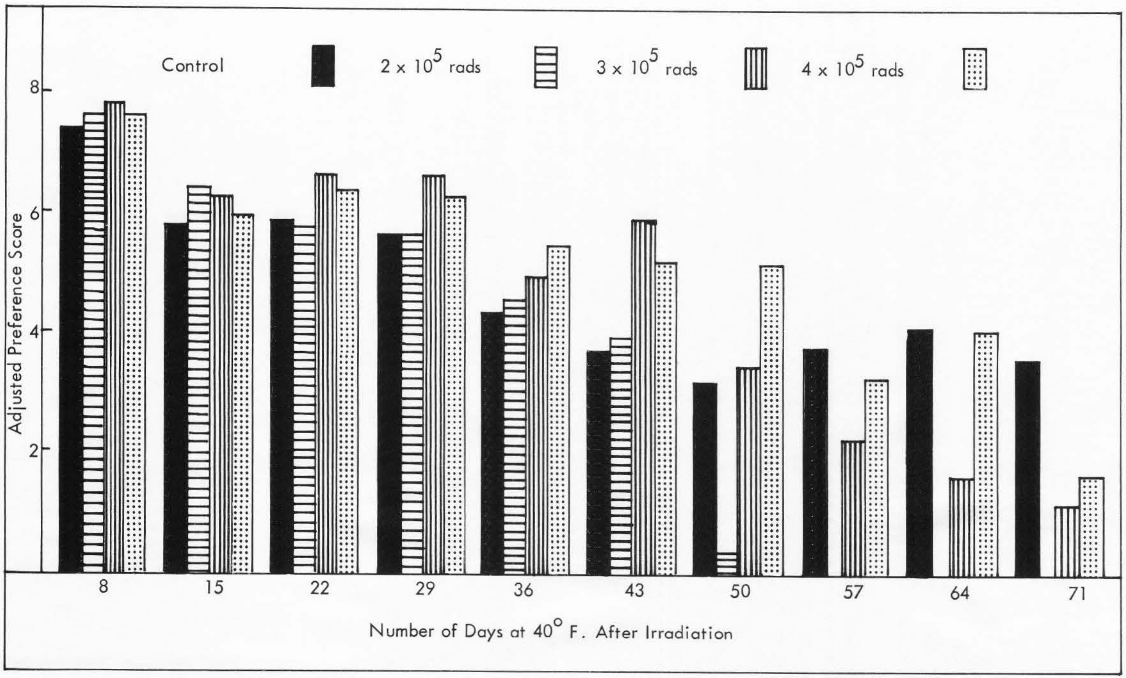

Figure 18. Effect of radiation dose on the adjusted preference score for Windsor sweet cherries stored at 40°F and evaluated after 8, 15, 22, 29, 36, 43, 50, 57, 64, and 71 days.

less rapidly than those of the control; those for Windsor cherries declined less rapidly at control. Scores for Lambert and Windsor cherries declined faster when irradiated at the 2×10^5 rads level than at any other dose. High scores for the cherries moved from the radiation dose of 2 to 4×10^5 rads after 22 days of storage, and then remained constant for the rest of the experiment. The highest score for the experiment was 8.2 (like very much) at 2×10^5 rads level for Bing and Lambert cherries at the eighth day of the storage period.

Figure 19 shows that the average adjusted preference scores for Napoleon cherries from the eighth to the seventy-first day decreased progressively with time, but the scores for the cherries irradiated at 2, 3, and 4×10^5 rads levels decreased more rapidly than those at control. From the eighth through the forty-third day of storage, the adjusted preference scores for each sampling day were directly related to the radiation dose, i.e., as the radiation dose advanced from control to 4×10^5 rads levels at each period, the overall adjusted scores increased. During the last four storage periods, scores were inversely related to the radiation dose, i.e., as the radiation dose advanced from 1 to 4×10^5 rads levels, the overall adjusted preference scores decreased. High scores shifted to 2×10^5 rads at the fiftieth day of storage and then to control for the rest of the experiment.

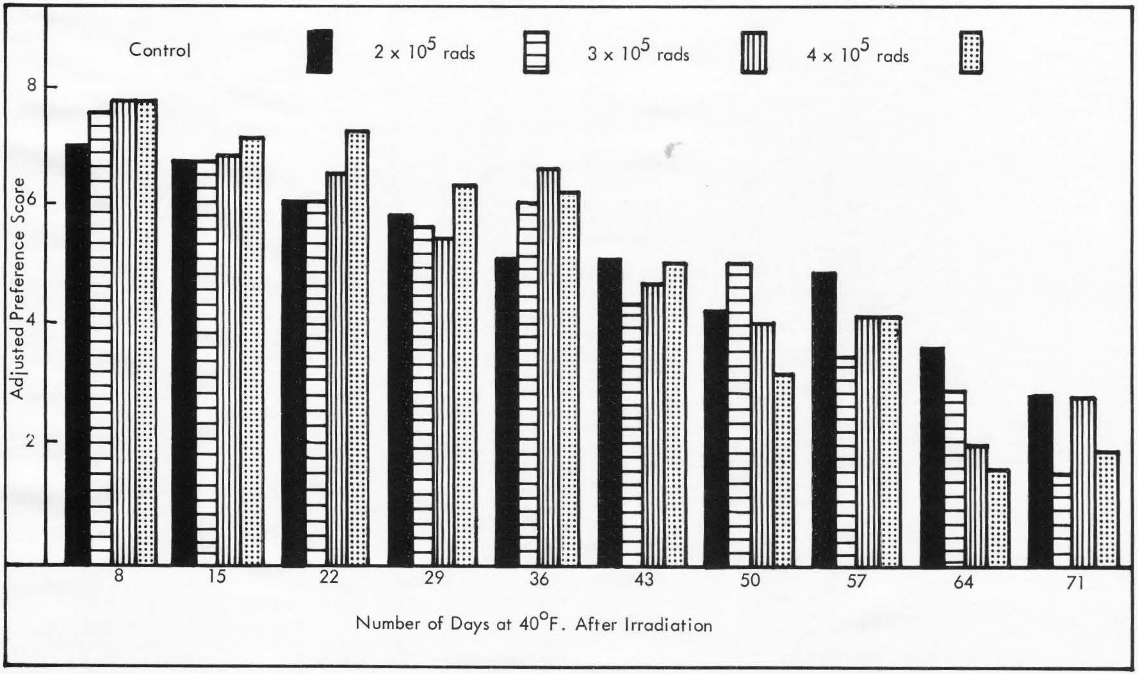

Figure 19. Effect of radiation dose on the adjusted preference score for Napoleon sweet cherries stored at 40°F and evaluated after 8, 15, 22, 29, 36, 43, 50, 57, 64, and 71 days.

DISCUSSION

It is known that gamma radiation controls the sprouting losses (25, 31), inhibits the microbial growth (5, 7, 9, 12, 13, 14, 16, 18, 29, 33, 35), insect infestations (30), and slows down the ripening process of fruits and vegetables (37, 40). Still the irradiated product should be acceptable to the consumer. Hence, flavor, color, and texture are the important factors of irradiated fruits and vegetables which need to be considered before they become a commercial reality.

Flavor

The most important factor in the acceptability of a product is its flavor. It has been found from the studies conducted by Gerber *et al*. (13, 14), Kraybill (21), and Salunkhe *et al*. (41) that the effective radiation doses for radio-pasteurization without loss in acceptability is below 5×10^5 rads. The author's observation is that the pasteurization dose varies from crop to crop. For example, sweet cherries can withstand radiation doses up to 4×10^5 rads without much alteration in the quality. However, in the case of strawberries, 3×10^5 rads is the maximum level. Also, varieties within a given crop vary to the dose requirements. Kasuga and Sparkle were varieties better suited for radio-pasteurization than the others studied. In this regard, firmness of a variety has much to do to influence its flavor. Because Marshall was not a firm variety, during and after irradiation the berries disintegrated much faster with resultant loss of flavor, in contrast to Kasuga and Sparkle which were firmer varieties. It should also be noted that maturity of the crop is an essential factor. It can be assumed that when the fruit is irradiated in the green stage it does not develop natural flavor, perhaps because esters, alcohols, and other flavor constituents do not develop properly and/or they are destroyed by gamma radiation; whereas, if it is irradiated at the overripe stage the flavor components disintegrate much faster.

Color

It has been found by the author as well as by others (11, 24, 34, 40), that the bleaching and discoloration of strawberries were apparent after irradiation. The intensity of the bleaching was directly related to the storage duration. This bleaching could be attributed to the degradation of anthocyanins. Kraybill (21) and Salunkhe et al. (40) also reported that the anthocyanins were more radio-sensitive than other pigments such as chlorophylls and carotenoids. It has been reported that ascorbic acid is the most radio-sensitive vitamin (36). Its degradation could make fruits susceptible to oxidation; hence, the bleaching or oxidation of anthocyanins in strawberries might have taken place.

Burns and Desrosier (3), Rivers (37), and Salunkhe et al. (41), working with tomatoes have shown that gamma radiation at pasteurization dose levels slowed down the ripening and pigment development. This concurs with the author's findings on strawberries, when strawberries were irradiated in the green stage of maturity. They did not fully ripen, nor did the color develop as the non-irradiated controls did.

Mechanism of browning as a result of radiation is not known in detail because of many interrelated factors; some of which may be as follows:

1. Availability of substrates to increased activities of enzymes.
2. Increased oxidation of polyphenols to assist in the development of brown color.
3. Hydrolysis of starch to sugars and subsequent condensation with protein fractions, ascorbic acid, and/or tannins.
4. Degradation of vitamins and pigments.
5. Cumulative effects of above-mentioned factors may enhance the browning reaction in irradiated fruits at an elevated temperature (during the radiation process), and with a time lag.

Texture

Radiation induced softening of fruits may be caused by the partial or complete breakdown of simple and complex carbohydrates such as pectins and cellulose of the cells and cell wall structures (27, 39, 40) with resultant texture loss and softening of fruits and vegetables (25, 40).

It is, therefore, recommended that strawberries as well as sweet cherries be irradiated at 3×10^5 and 4×10^5 rads, respectively, at the firm-ripe stage of maturity to retain maximum flavor, color, and texture.

SUMMARY AND CONCLUSIONS

Studies were conducted in 1959-60 on the effects of gamma radiation on strawberry varieties--Kasuga, Lindalicious, Sparkle, Marshall, Robinson, and Shasta, and sweet cherry varieties--Bing, Lambert, Napoleon, and Windsor. In general, results showed an increase in shelf-life at refrigeration ($40^{o}F$) temperature with increase in radiation dose, but the organoleptic quality of the fruit declined progressively as the storage period was extended. However, the adjusted preference scores were progressively higher as the radiation dose advanced, which would indicate that radiation inhibited mold growth and thus increased acceptability and extended the refrigerated-life of these products.

The keeping quality of strawberries and sweet cherries at $40^{o}F$ can be increased by radiation by an additional 15 to 30 days, respectively. The non-irradiated controls became unacceptable at the end of 15 days' storage for strawberries, and 40 days for cherries. In general, 2×10^5 rads dose was the optimal dose of radiation for the preservation of strawberries; and 3×10^5 rads dose, for sweet cherries without much loss in quality.

Kasuga and Sparkle strawberries and Bing sweet cherries were more suitable varieties for the radiation treatment than any others studied. The green tip stage of maturity of strawberries and firm-ripe stage of maturity of cherries were the best stages for radiation preservation. Strawberries which were irradiated when green did not ripen, while those that were overripe became soft and spongy.

All varieties of strawberries with the exception of Kasuga and Sparkle exhibited varying degrees of bleaching at 2 and 3×10^5 rads. For sweet cherries as the storage period increased, non-irradiated cherries became riper and darker, but those irradiated at 2, 3, and 4×10^5 rads levels exhibited less ripening. As the radiation dose advanced from 1 to 4×10^5 rads, the flesh of Bing, Lambert, and Windsor cherries became progressively lighter in color.

Throughout the experiment a peculiar, spongy, soft texture was observed in all varieties of strawberries at 3×10^5 rads. The number of soft berries increased as the storage period was lengthened.

Napoleon cherries at 2, 3, and 4×10^5 rads levels developed a brown discoloration early in the experiment. This discoloration became progressively worse with increased storage.

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